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NUCLEAR WEAPONS AND PROTECTION AGAINST NUCLEAR WEAPONS

By

Manfred Hoffmann

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NUCLEAR WEAPONS AND PROTECTION AGAINST NUCLEAR WEAPONS

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[Text] Foreword

In a series of imperialist countries, especially in the United States, nuclear weapons are being further developed, new delivery vehicles are being created and are being introduced into the armies regardless of all protests of peace-loving humanity. Stockpiles of nuclear charges are being increased and are constantly kept in readiness in arsenals of the armed forces.

Contrary to the specific proposals by the Soviet Union and other socialist states during the disarmament negotiations concerning a universal ban on the manufacture, stockpiling, and use of nuclear weapons, the United States and some other imperialist countries so far have declared themselves only ready to enter into certain partial agreements in some fields.

In case a war should be unleashed against the socialist states and in case of other wars, the United States is still threatening to use nuclear weapons. In this connection, detailed instructions were drafted regarding the authority of NATO unit commanders for nuclear weapons employment and a "theory of escalation" of weapons employment was devised.

As far as our units are concerned, this creates the need for devoting undiminished attention to nuclear defense measures during training.

This textbook takes up the most important combat properties and destructive effects of nuclear weapons and from that we derive and explain the necessary unit nuclear defense measures. This book is designed for study at the "Friedrich Engels" Military Academy and other college installations under the Ministry of National Defense, for individual independent study by officers of the various armed agencies and other interested parties. It cannot and should not replace the service regulations concerning these areas. Its objective instead is to support the study of theoretical basic problems of nuclear weapons and nuclear weapons defense through systematic and as realistic as possiblé illustration for the group of readers who, in their work, will primarily have to come to grips with semistrategic and tactical problems. This is why a strict dividing line was drawn in the selection of the subject matter. The individual problems and situations were identified in keeping with their significance through differing description. Both with the help of the reference notes given with each chapter and with the help of the large bibliography it was made possible quickly to gain access to special problems. The review questions included in the individual chapters can serve as guidance for the main points to be covered especially during individual independent study.

It will be the job of all officers working with this book to contribute to its further improvement by passing on critical comments and lessons learned.

Lieutenant General Prof. Wiesner

0. Introduction

So long as imperialism exists, there is the danger that aggression might be unleashed against the socialist states.

For the sake of the reliable protection of further socialist construction and to guarantee peace in Europe, the National People's Army must during every development phase have the necessary high level of combat readiness and it must be prepared, together with the Soviet Army and the other brother armies of the states of the Warsaw Treaty effectively to counter any possible aggression and to wipe the aggressor out on his own territory.

In keeping with the NATO concept and the plans of the imperialist circles in the FRG, we must expect that aggression might begin both as a concealed or limited war or as a general nuclear war.

A war involving the use of nuclear weapons would create the very highest requirements for the troops among all of the possible variants of a possible armed conflict.

"All this makes it obvious for us to conclude that the armed forces of the Soviet Union and the other socialist countries must primarily prepare for a war in which both states (the United States and the Soviet Union--the author) will make massive use of nuclear weapons. This is why one must consider the scientific solution of all theoretical and practical problems, which arise from the preparation for such a war and its conduct, as the primary mission here."[1]

Developments in the nuclear weapons field are characterized not only by the steady increase in stockpiles of nuclear charges by the nuclear powers but also by the further perfection and creation of new systems for their employment and the rapid introduction of these systems into the armed forces.

The detonation equivalents have grown from the kiloton range to the Megaton range. Here, the scale of payloads and delivery vehicles extends from missiles via airplanes and various artillery systems to nuclear mines.

This equipment of the armed forces with the most varied kinds of nuclear devices took place within the overall context of the revolution in military affairs, the new equipment and re-equipment of the armed forces and their reorganization, the drafting of a military doctrine and art of war which will do justice to the requirements of a possible worldwide nuclear missile war, the drafting of new combat regulations, etc., whereby nuclear weapons represent not only the most essential element but also the cause of many other upheavels in the military-science and military-engineering field--and not here alone either.

By virtue of their annihilating and destructive effects, nuclear weapons by far not only exceed all previously known means of annihilation but also differ from them qualitatively. Here the effects of a nuclear weapon are very manifold and they depend in each case on the specific conditions of the

particular detonation. A nuclear weapons detonation is characterized by the fact that, in addition to the immediately effective annihilation factors, there can also be extensive aftereffects in the form of crater formation and the radioactive contamination of the terrain. As a result of massive nuclear strikes, especially following surface and underground detonations, there are vast areas which are destroyed and which are radioactively contaminated with high dose exposures; they can exert universal influence on the preparation, the course, and the outcome of combat operations and they can have an essential effect on the work of the various headquarters, the actions of the troops, and measures to provide backup support for combat and operations.

The planning, organization, and implementation of nuclear weapons defense for the units in the field requires commanders and staffs to have comprehensive tactical-semistragetic and natural-science-technical knowledge and creates the very highest requirements for the unit command as such. Nuclear defense is an integrated component of unit defense against mass annihilation weapons.

In all types of combat and in any situation, this nuclear defense must be organized with the objective of diminishing the effects of enemy nuclear weapons employment to the maximum extent, preserving the combat value and combat readiness of our troops, or restoring them quickly after nuclear strikes by correcting the consequences and guaranteeing the accomplishment of the assigned mission.

Unit nuclear defense is essentially achieved through the following:

Timely reconnaissance of enemy preparations for the use of nuclear weapons and the prevention of the employment of such weapons;

Advance determination of radioactively contaminated areas as well as the precise indication of areas in which there will be extensive destruction, fires, or floods resulting from the use of nuclear weapons;

Constant nuclear radiation monitoring;

Timely warnings for the troops and for rear-echelon support units concerning radioactive contamination;

Decentralization and camouflage of field units and rear-echelon support units;

Alternation of unit bivouac areas;

The use of individual protective gear as well as the utilization of the protective properties of combat vehicles, the terrain, and cover;

Preparation of roads for maneuvers and for Engineer-level improvement of areas to be taken up by the troops;

Effective and efficient action in contaminated areas;

Dosimetry and nuclear radiation monitoring in the platoons and companies;

Timely and steady supply of units with protective equipment;

Rapid elimination of the consequences of enemy nuclear strikes.

1. Classification, History, and Structure of Nuclear Weapons

1.1. Principles of Subdivision and Fundamental Concept Definitions

Nuclear weapons are mass annihilation weapons. At this time there are three major groups of mass annihilation weapons: Nuclear weapons, chemical weapons (CW agents), and biological weapons (BW agents).[2]

The essence of mass annihilation weapons consists in the fact that their injuring or destructive effects always extend to a more or less large and continuous surface area, that, compared to the means of application, tremendous effects are produced, and that the effects of their employment as a rule cannot be confined only to the militarily necessary degree.

Each group of mass annihilation weapons has specific combat properties and annihilation effects. This is why the determination of a clear sequence is hardly possible. Nevertheless, nuclear weapons hold primacy inasmuch as they are not directed practically exclusively against human beings, such as chemical and biological weapons, but rather produce heavy destruction of combat equipment, buildings, installations, etc.

The general concept of "nuclear weapons" encompasses all types of weapons whose annihilating and destructive effects are based on the release of nuclear energy.

It is basically possible, first of all, through certain unguided nuclear reactions to release nuclear energy in the form of a detonation and, besides, to utilize the nuclear radiation, which is released as a result of the decay of natural or artificial radionuclides, as the sole annihilation factor.

Detonating nuclear weapons are weapons in which the release of energy is based on the foundation of nuclear fission and/or nuclear synthesis reactions in the form of detonations. Radioactive warfare agents are radionuclides which have been assembled especially for wartime use; they can be employed in various aggregate states and with different means and methods.

In the following we will use the term nuclear weapon always in the sense of "detonating nuclear weapon" while on the other hand we will be speaking of radioactive warfare agents.

Nuclear weapons can be arranged according to a series of viewpoints:

According to the type of energy released;

According to the detonation intensity (the detonation equivalent);

According to the type of nuclear charge employed;

According to the military purpose or the devices used.

Concerning the basic schemes of energy release, we can basically distinguish nuclear fission weapons and nuclear synthesis weapons.

Nuclear fission weapons are nuclear weapons in which the detonation energy is produced by the fission of heavy, energy-rich nuclei into heavy nuclei which are poorer in energy, in the process of thermonuclear reactions.

In keeping with the course and type of energy release, we can furthermore distinguish between single-phase and multi-phase nuclear weapons.

The term single-phase nuclear weapons is applied to those nuclear weapons where the energy release is based either only on nuclear fission or only on nuclear synthesis.

Multi-phase nuclear weapons are nuclear weapons where the detonation energy is released in succession through nuclear fission and nuclear synthesis reaction in two or three phases (nuclear fission--nuclear synthesis--nuclear fission).

Nuclear fission weapons and nuclear synthesis weapons thus are single-phase nuclear weapons corresponding to the concept definitions given here.

In using the terms mentioned we must keep in mind that no uniform terminology has so far prevailed both in military language and in the pertinent literature. For example, in place of the concept of multi-phase nuclear weapons we still frequently have the concept of nuclear synthesis weapon or thermonuclear weapons although the energy from these nuclear weapons does not exclusively stem from nuclear synthesis.[3]

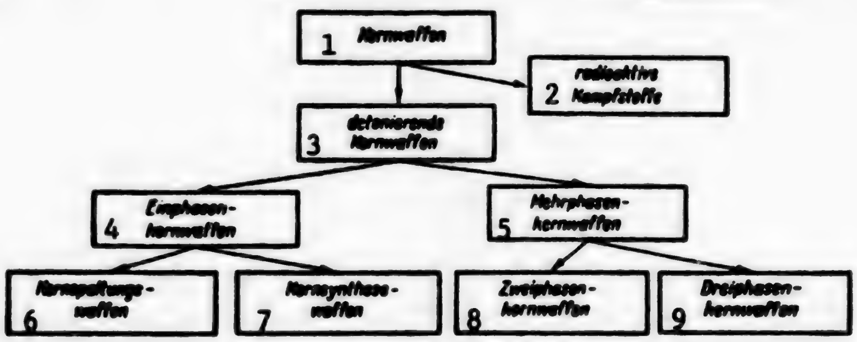


Figure 1.1. Classification of nuclear weapons in accordance with energy release. Key: 1--Nuclear weapons; 2--Radioactive warfare agents; 3--Detonating nuclear weapons; 4--Single-phase nuclear weapons; 5--Multi-phase nuclear weapons; 6--Nuclear fission weapons; 7--Nuclear synthesis weapons; 8--Two-phase nuclear weapons; 9--Three-phase nuclear weapons.

The detonation intensity is the most important characteristic of nuclear weapons.

The detonation intensity is a measure of the total energy released as a result of the detonation. It is given in equivalents (t, kt, Mt) of Trinitrotoluene (TNT).

In all formulas given in this book, the detonation intensity is always to be inserted in terms of kt TNT.

The detonation intensity of presently available nuclear weapons is roughly within the limits of 0.005 kt TNT to 100 Mt TNT.

This means that connection downward is established to the calibers of conventional ammunition. Upward, a further increase in the detonation intensity is physically and technically conceivable but militarily hardly meaningful.

We can schematically subdivide nuclear weapons as follows, as a function of the detonation intensity:

Small detonation intensities:	$q \leq 15$ kt TNT
Medium detonation intensities:	15 kt TNT $< q \leq$ 100 kt TNT
Large detonation intensities:	100 kt TNT $< q \leq$ 500 kt TNT
King-size detonation intensities:	$q >$ 500 kt TNT

The nuclear weapons criminally employed against Hiroshima and Nagasaki by the American imperialists in 1945 had a trotyl equivalent of about 20 kt. This detonation intensity is often used as a comparison value and is therefore referred to as the "standard bomb."

A detonation intensity of 100 Mt TNT implies an increase in the detonation energy at a ratio of 1:5,000.

In this kind of estimate one must however keep in mind that the annihilation radii do not grow simply in proportion to the detonation intensity but increase considerably more slowly. On top of that we furthermore have the fact that the detonation intensity, expressed in trotyl equivalents, is only a measure of the magnitude of the total energy released during a detonation whereas regarding the distribution of that energy over the individual annihilation factors, no simple comparison to conventional ammunition is possible.[4]

In purely physical terms, a smooth transition is possible in the range of detonation intensities mentioned here. Considering the tactical-technical data on nuclear weapons devices, we however get certain standard detonation intensities which make it possible to evaluate the consequences of enemy nuclear weapons strikes.

The type of nuclear charge used likewise does influence the characteristic of a nuclear weapon.

The radionuclides U-235 and Pu-239 are used mostly in nuclear fission weapons.

The hydrogen isotopes deuterium and tritium are used—mostly in the form of lithium compounds--in nuclear synthesis weapons or in multi-phase nuclear weapons.

U-238 is used for the release of nuclear fission energy by means of super-fast neutrons.

The nuclides that can be used for nuclear fission differ essentially in terms of their critical parameters. For example, the size of the critical charge mass of Pu-239 is only about 25 percent of that of U-235.

This necessarily results in differentiated design principles for the individual nuclear weapons types. On top of that we have the fact that nuclear explosives also differ greatly in terms of their miscellaneous physical and chemical properties. Something similar applies to nuclear synthesis materials. Here, for example, the aggregate state, in which they are normally present, plays a very great role. Another viewpoint is derived from the differing ignition temperature and the resultant highly variable course of thermonuclear processes as a function of the composition of the nuclear synthesis charge.

Some other viewpoints will be covered in greater detail in connection with the individual nuclear weapons types.

By way of guidance we might estimate that nuclear fission weapons of up to about 300 kt TNT can probably be made. In practice however the upper limit would be around 100 kt TNT. Two-phase nuclear weapons (addition of nuclear synthesis material) are best suited for detonation intensities of several hundred kt TNT. Nuclear weapons in the Mt range are most probably based on the three-phase principle. But it is also possible to bring about very great detonation intensities with a high nuclear synthesis share. Conclusions can be derived from several test series.

The means of delivering a nuclear charge to a target are very manifold. At the end of World War II and during the years immediately thereafter, nuclear weapons existed practically only in the form of bombs. Today, nuclear charges are delivered primarily by missiles. The combination of missile and nuclear weapon, the nuclear missile, represents a completely new quality of fire. It forges the technical character of a possible world war as a nuclear missile war. Prior development of weapons in engineering terms as well as nuclear warheads, as delivery vehicles or devices, makes it possible today to use nuclear weapons universally, over any desired range, against the most varied targets under all meteorological conditions.

Nuclear weapons can be used by all services. Specifically, they can be used in the following ways (some of the NATO devices are given in parentheses):

Ground-to-ground missiles for tactical, semistrategic, and strategic uses, with nuclear charge ("Lance"--up to 70 km, "Sergeant"--up to 140 km, "Pershing" --up to 740 km, "Minuteman"--up to 13,000 km);

Ground-to-air missiles (AA missiles to engage manned and unmanned air attack systems, ABM's) with nuclear charge ("Nike-Hercules"--30 km altitude);

Aircraft (nuclear bombs and air-to-ground missiles with nuclear payload) ("F 84 F Thunderstreak," "F-100 D Super Sabre," "F-4 C Phantom," "HSD Blue Steel" air-to-ground missile--up to 320 km after firing from aircraft);

Conventional artillery pieces (roughly from 150 mm on up) in the form of nuclear shells (155-mm SP howitzer, M-109, up to 18 km, 203.2-mm SP howitzer, M-110, up to 16 km);

Submarines, especially nuclear-powered, in the form of underwater--ground missiles with nuclear charge or torpedoes with nuclear charge ("Polaris" --up to 4,000 km);

Surface vessels with corresponding missile or torpedo armament;

Nuclear mines used by ground forces and naval forces;

Outer space systems.

The means for the employment of nuclear weapons to accomplish strategic assignments above all include intercontinental missiles, long-range missiles, but also medium-range rockets, strategic air units, and submarines as well as outer space weapons. Here one uses primarily nuclear weapons with detonation equivalents on the order of magnitude of several hundred kt TNT up to several tens of Mt TNT.

In the semistrategic-tactical context, short-range and medium-range rockets, fighter-bomber units, certain artillery systems, and mines are especially used as nuclear weapons.

Ground forces operations can partly be supported along the coastline through nuclear weapons employed by naval forces. The detonation intensities of semistrategic-tactical nuclear weapons as a rule cover a range extending from several kt TNT to several hundred kt TNT.

One special aspect of nuclear weapons development in recent years consists in the fact that the transition to multiple nuclear charges was accomplished especially in the strategic systems. In this way, several nuclear warheads can be aimed against one or several targets with a single delivery vehicle.

Although examples of this type become obsolete very quickly, we might mention here the American MRV and MIRV series systems. In the MRV system, for example, just one missile of the Polaris A-3 type can carry three nuclear warheads which, after their separation from the booster, reach their target in a ballistic form.

In the case of the MIRV system, the individual nuclear charges have an additional engine of their own and are used in a program-controlled manner against individual targets within a radius of up to 200 km.

The "Minuteman" can thus carry three nuclear warheads at 200 kt TNT, each, while the "Poseidon" can carry ten nuclear warheads at 50 kt TNT, each, including as many as four decoys.[5]

The most effective nuclear defense measure consists in annihilating enemy nuclear weapons systems before they are in a position to use nuclear weapons.

This goal requires specific knowledge of the employment principles of enemy nuclear weapons, their storage, movement, supply, etc., their constant observation and a readiness immediately to engage them after the appearance of such a target, using all available means, especially the systems of the rocket forces and the artillery on duty.

As we hinted earlier, nuclear weapons systems are constantly changing. Because, other things being equal, the annihilation effects of a nuclear weapon are relatively independent of the delivery vehicles, questions connected with that will not be subjected to any further consideration below.

Review Questions

1.1. What viewpoints must be considered in the concept definition of mass annihilation weapons?

1.2. What are the characteristics according to which we can arrange nuclear weapons and what practical conclusions can be drawn from that?

1.3. Why is the detonation intensity of a nuclear weapon not simply comparable to the effect of conventional weapons?

1.4. What kinds of nuclear weapons systems are presently available to NATO and what are the resultant conclusions concerning unit nuclear defense?

1.5. What is the most important nuclear defense measure and how can it be implemented.

1.2. The Most Important Stages in the History of Nuclear Weapons

The physical, chemical, and engineering prerequisites for the creation of nuclear weapons in the middle of this century were the numerous outstanding results from the natural sciences, especially atomic and nuclear physics, and the very highly-developed industry in the Soviet Union and in the leading imperialist countries.

The actual early history of nuclear weapons begins in December 1938 with the discovery of atomic nuclear fission through the action of neutrons by the German physicist Otto Hahn.

Theoretical studies conducted after this discovery already in 1939 revealed that tremendous quantities of energy could be obtained on the basis of nuclear fission under certain prerequisites. Until that time, by far most of the physicists were of the opinion that practical utilization of nuclear energy was not possible because the energy amount to be used for nuclear conversion was greater than the amount released as a result.

Hahn's discovery put the entire situation into a completely new light.

If we look at the international political situation at that point in time, we can understand that all further publications were suddenly cut off. In secret however physicists in a whole series of countries looked into the phenomenon of nuclear fission and also tried to fathom the resultant consequences.

These consequences could indeed be monstrous because after all German fascism was already getting ready to implement its aggressive goals by unleashing a world war.

In the United States, a group of scientists, headed by L. Szilard, persuaded Albert Einstein to contact President F. Roosevelt and to explain to him the military significance of the discovery of nuclear fission through neutrons and to propose the conduct of secret research.

Practical work on the "Manhattan Project" finally began in August 1942. This was the code name for all scientific, technical, military, and administrative measures which in the end were supposed to lead to the construction of a nuclear bomb and its employment.

During the 1940's, the United States had become a stronghold of nuclear physics. A. Einstein had emigrated from Germany while E. Fermi and E. Segre had come from fascist Italy. Nils Bohr came from Denmark. On the basis of this tremendous scientific capacity, backed up by a highly-efficient, undestroyed industry, work quickly progressed in spite of tremendous natural-science and technical difficulties. Los Alamos, the R. Oppenheimer laboratory, became the center for the design and construction of the bomb.

In addition to those already mentioned, Oppenheimer had working with him such well-known scientists as E. O. Lawrence, J. Dunning, and H. Bethe.

To obtain the necessary nuclear explosive, efforts were relatively quickly concentrated on three of the original five methods contemplated.

On 2 December 1942, Fermi recorded the first chain reaction in the graphite pile built by him.

On the basis of lessons learned until then, four big breeder reactors were built in Hanford, Washington, to produce Pu-239. The first plutonium shipment went to Los Alamos in January 1945.

Huge installations for the separation of the uranium isotope U-235 (share 0.7 percent) were built in Oak Ridge, Tennessee. A gaseous diffusion plant and an electromagnetic separation plant were built. The gaseous diffusion plant began to operate in January 1945 (at a cost of more than M1 billion); the enriched U-235 was then further processed in the electromagnetic plant so that an adequate quantity of U-235 was likewise ready for shipment to Los Alamos in June 1945.

By the middle of the year, the United States finally had three "atomic bombs." The sum of $2 billion was invested to attain this goal.

The first experimental detonation of a nuclear fission bomb based on the implosion principle took place at 0530 on 16 July 1945 at the Alamogordo Air Base in New Mexico. The detonation intensity of the 214-t experimental device, which was set off on a 30-m high steel tower, was 10 kt.

This first experimental detonation was followed on 6 and 9 August 1945 by the senseless and criminal bombing by the American imperialists on the two Japanese cities of Hiroshima and Nagasaki.

The nuclear detonations caused fearful losses among the defenseless and unknowing population.

Table 1.1. Effects of Nuclear Bombs Dropped on Hiroshima and Nagasaki[7]

		Hiroshima	Nagasaki
1	Gesamtbevölkerung	300000	200000
2	Bevölkerungsdichte je km²	14000	25000
3	Tote	80000	40000
4	Verletzte	70000	40000
5	sofortige Erste Hilfe brauchten	85000	50000
6	Todesrate je zerstörten km²	6000	8000

Key: 1--Total population; 2--Population density per km^2; 3--Dead; 4--Injured; 5--The following required first aid; 6--Death rate per km^2 destroyed.

Other figures were given in various publications. This is due to the fact that, because of wartime events, no precise data were available on the population statistics for both cities; besides, it is very frequently impossible to determine under what conditions the loss estimates were made.[8]

The size of the total area destroyed in Hiroshima was about 12 km^2 and in Nagasaki it was about 5 km^2.

The report by the United States Strategic Bombing Survey[9] among other things contains the following passage on the Hiroshima and Nagasaki raids: "A single atomic bomb was detonated at 0815 (0915 local time, Tinian time--the Author) on 6 August 1945 over Hiroshima. Most industrial workers had already started work but many were still on their way; almost all school children were busy putting up firebreaks or moving valuables out into the country.

"The raid took place 45 minutes after a prior all-clear. Because no air raid alarm was sounded and because the population in view of the few aircraft did not feel particularly worried, the detonation came as an almost complete surprise. Most people were taken by surprise out in the open or at home. The bomb blew up somewhat northwest of the city center. Because of the accurate bombing, the level terrain, and the circular layout of the city, Hiroshima was

devasted uniformly and comprehensively. The entirely heavily built-up part of the city was practically levelled to the ground due to blast and fire. A firestorm arose. And, 3 days later, Nagasaki was hardly any better prepared. The day was clear, there was almost no wind--a usual summer day. The continuing air raids against the population of the city and the harshness of the summer led to a certain neglect of air raid protection measures. The preliminary alert was sounded at 0748 and it was followed by the alarm as such at 0750; the all-clear was sounded at 0830 and the population's alertness yielded to a great feeling of calm. The city continued on the alert; but the air raid alarm was not sounded immediately when two aircraft of the B-29 type were sighted once again. The bomb was dropped at 1102 and the alert was not sounded until 1109. Only 400 persons were in the air raid shelters. At ground zero, almost everything had been levelled to the ground; no further reports came from that area immediately after the detonation."

In his memoirs, which were published in 1956, Truman--who as President of the United States at that time ordered the nuclear bombs to be dropped on the two cities of Hiroshima and Nagasaki--wrote the following: "In 1945, there took place so significant an event that our relations with the entire world were basically changed and that a new era was announced to mankind, an era whose consequences, as well as the objectives and problems it raised, we still cannot fully gauge at this time. This event is the production of the atomic bomb."[11]

What, in the view of American imperialism, was the essential content of these new relations?

Yesterday as today the imperialist circles in the United States try to explain that the rapid development of the American nuclear weapons system was necessary to get ahead of fascist Germany and that the use of the nuclear bombs against Japan supposedly forced that country into rapid capitulation and thus put an end to World War II.

If we follow the rational core of the investigations by D. Irving[12] concerning research in the field of nuclear weapons in fascist Germany and in the United States during World War II, we may, in the light of present-day knowledge, admit that some of the scientists involved in the Manhattan Project in their work were guided by concern over the fate of humanity threatened by fascism.

But this approach is only half the truth. Very soon, those scientists lost every right to have any say on the use of their work results.

Concerning Japan's capitulation, it was speeded up inasmuch as certain circles in the Japanese government which were inclined toward capitulation in this way with renewed clarity received a demonstration of the hopelessness of the military situation. This capitulation however in the final analysis was the result of the Soviet Union's entry into the war against Japan and the smashing of the main body of the Japanese army, the Kwantung army, in Manchuria. This clearly shows that the leading circles in the United States were quickly concerned with testing the new weapon under "specific" conditions and thus to tackle far-ranging political objectives.

The British physicist Blackett mentions these objectives as he writes that "dropping the atomic bombs was not so much the last military act of World War II but rather one of the first major operations in the cold diplomatic war against the Soviet Union."[14]

In view of the effects of these detonations, the leading circles in America at that time adopted the mistaken belief that "by threatening to use the atomic bomb, it would be possible to force the Soviet Union—no more and no less— to drop socialism and to restore capitalism."[14]

It thus becomes clear with brutal openness that it was not so much America's fear of having Hitler Germany get ahead of it in the production of the first nuclear weapons which caused the American effort to make a maximum effort but rather from the very beginning the endeavor to use this new weapon as a means of threatening and blackmail and thus to carry out the United States' plans for world rule.[15]

Former President Truman did not feel any remorse later on over the fact that he gave the order to wipe out more than a hundred thousand innocent people in Hiroshima and Nagasaki. Early in November 1961 he made the hideous statement in addressing the National Press Club in Washington to the effect that he would at any time repeat the order to drop atomic bombs on both of these Japanese cities.[16]

The trotyl equivalent of each of the two nuclear bombs dropped on Hiroshima and Nagasaki was about 200 kt (20,000 t). But the previously mentioned report by the United States Strategic Bombing Survey shows that formal comparisons make little sense. Here we find the following calculations: "On the basis of the known destructive power of various bombs and on the basis of experiments, the bombing survey figured out what bomb load would have been necessary to cause the same destruction in Hiroshima and Nagasaki. In Hiroshima, it would have been necessary to drop 1,300 t of bombs (consisting of one quarter He and three quarters of incendiary bombs) and in Nagasaki it would have been necessary to drop 600 t bombs (three quarters He and one quarter incendiary bombs). Besides, in Hiroshima, 500 t of fragmentation bombs and in Nagasaki 300 t of fragmentation bombs would have been necessary to cause similar human losses. The total bomb load thus would have been as follows: 1,800 t in Hiroshima and 900 t in Nagasaki. If each aircraft carries 10 t, then we would have had to send 180 B-29 bombers against Hiroshima and 90 B-29 bombers against Nagasaki."[17]

The nuclear payload came to about 50 kg both in the Hiroshima bomb (U-235, "gun principle") and in the Nagasaki bomb (Pu-239, implosion principle).

The energy balance shows that, of that amount, about 1 kg were split in each case and that the efficiency thus was 2 percent.

The total weight of each nuclear bomb (including bomb carrier, chute, etc.) was about 5 t. The detonation altitudes were at 600 m or 350 m.

The nuclear armament effort of the United States did not terminate or was not slowed down upon Japan's capitulation and the end of World War II; instead,

it assumed unimaginable proportions. Huge armament industry plants were built and hundreds of thousands of people were employed in them. The United States had a nuclear weapons monopoly and used it as a weapon in the Cold War. With all available means, the United States tried to perfect nuclear weapons and to establish corresponding stockpiles in order to give its policy of strength the necessary emphasis against the Soviet Union. That goal was also served by renewed nuclear weapons tests. The so-called "Abel Bomb" was exploded on 1 July 1946 at an altitude of 500 m between the aircraft carrier "Independence" and a Japanese cruiser as the first surface detonation over water.

The second test followed in the region of Bikini Atoll on 25 July 1946; this was an underwater detonation.

This development was naturally watched very carefully by the Soviet Union. Based on the advantages of the socialist social system, the CPSU and the Soviet government mobilized all available scientific and technical capacities in order to be able to begin with the development, manufacture, and testing of nuclear weapons.

Looking back, A. P. Aleksandrov writes the following on this: "I. V. Kurchatov and the other scientists, engineers, and experts from the most varied fields --who worked on the Soviet atomic project by order of the Central Committee of the CPSU--clearly realized that the development of an equivalent weapon--even before the United States had gone into the mass production of atomic weapons--was a question of life or death for the defense of the Soviet Union."[18]

In the summer of 1939, the Soviet physicists Ye. B. Zeldovich and Ye. B. Kharitov provided theoretical proof to the effect that the chain reaction of nuclear fission was real and in this way they created certain foundations for the theory of the chain reaction.

In the autumn of 1940, I. V. Kurchatov made a general analysis of the possibilities of bringing about a chain reaction and in the process recognized the enormous difficulties which would stand in the way of practical implementation.

Back in 1939, he had already contacted the Soviet government with a reference on the military problems involved in nuclear fission. The fascist attack on the Soviet Union led to the destruction or evacuation of the laboratories in Kharkov and Leningrad. Moreover, the military situation forced the leading Soviet scientists to devote themselves to the immediate perfection of equipment for the Soviet armed forces.

With the turning point in the Great Fatherland War of the Soviet Union, scientific research then began in the field of uranium fission in 1942. A central study group was created in Moscow in 1943 under the direction of I. V. Kurchatov. The theory of nuclear reactors was developed already in the autumn of 1943 and the first Soviet uranium-graphite experimental reactor became operational on 25 December 1946. In addition to I. V. Kurchatov, the following of his closest collaborators participated in this outstanding event: I. S.

Panayuk, B. G. Dubrovskiy, Ye. N. Babulevich, and A. K. Kondratev. This meant that the "secret" of the production of plutonium, the nuclear explosive, had been discovered.

Parallel to this scientific effort, an efficient nuclear industry was planned and built up. While the imperialist circles in the United States figured on the Soviets getting their first nuclear weapon at the earliest in 1952, the then Soviet Minister Molotov was able to declare already on 6 November 1947 that the United States was no longer the only one to possess the secret of atomic bomb production.[19]

The first Soviet nuclear weapons test detonation took place on 29 August 1949. This meant that the nuclear weapons monopoly of the United States had been broken. The policy of strength had suffered a decisive defeat. But the Soviet Union did not yet have nuclear weapons stockpiles.

On 31 January 1950, Truman signed an order obligating the AEC to make every effort to create a "thermonuclear weapon."[20]

While the detonation equivalents in nuclear fission weapons were still counted in the thousands of tons of TNT, they now grew into the Megaton range. On 1 November 1952, the United States, on Elugelab Island, in the Pacific Ocean, for the first time conducted a test with a thermonuclear device (code name "Mike"). The detonation intensity was 5 Mt and it was thus 250 times greater than that of the Hiroshima bomb.[21] This was a pure test detonation which as yet did not permit any direct military use. The explosive as such weighed about 50 t. The gaseous hydrogen isotopes deuterium and tritium were used as nuclear charge during the synthesis phase.

On 28 February 1954, the United States triggered a second test detonation with an intensity of 15 Mt on Bikini Atoll. This was a transportable device.

On 26 March of the same year, another detonation of similar intensity followed on the Marshall Islands. It may be assumed that lithiumdeuteride (LiD) was used in both cases as nuclear charge.[22]

The enormous speed with which nuclear weapons development continued in the Soviet Union is pointed up by the fact that the first test detonation of a multi-phase nuclear weapon became possible already on 12 August 1953.

According to data from the United States AEC, lithiumdeuteride was used either partly or completely in place of the expensive tritium for nuclear synthesis already during this first experimental detonation. This also explains the fact that the explosive itself was transportable. Other "thermonuclear" test detonations followed in September and October 1954.

On 22 November 1955, the Soviet Union conducted the first air burst of a multi-phase nuclear weapon. The weapon was dropped from an aircraft. All prior thermonuclear detonations in the United States and the USSR until then had been ground bursts.

The first such air burst came off successfully in the United States only on 21 May 1956.[23] These facts show that the Soviet Union was in a position simultaneously to work on the problems of using nuclear fission and nuclear synthesis, finding favorable design solutions quickly, and thus, in the case of multi-phase nuclear weapons, arriving at militarily usable devices faster and creating corresponding stockpiles in shorter periods of time than the United States--all this in spite of the vast losses and damage caused by the fascist attack and more unfavorable economic preconditions.

Even the tremendous efforts of the United States during the following years were unable to change anything on the fact that balance of power was always shifting in favor of the Soviet Union also in the field of nuclear weapons.

In 1953-1957, equality was achieved in nuclear weapons development between the Soviet Union and the United States; during the years thereafter, the Soviet Union gained superiority. On top of that we have the fact that the Soviet Union, parallel to the nuclear warheads, also developed the required delivery vehicles. Thus, TASS [Telegraph Agency of the Soviet Union] on 27 August 1957 reported that the first intercontinental missile had been tested in the Soviet Union. On 4 December 1962, Marshal Biryuzov in the army newspaper KRASNAYA ZVEZDA reported that the Soviet Army had warheads of 50-60 Mt for intercontinental missiles. This meant that even the United States itself was no longer invulnerable.

In recent years the United States again and again tried to make its alleged superiority credible in the field of nuclear weapons. To do that, it used above all the loyal monopoly press to propagate ever new variations of "modern nuclear weapons." Here are some examples.

In 1957 came the so-called "clean bomb," that is to say, a nuclear weapon with less radioactivity (energy release exclusively based on nuclear synthesis); it was touted as being particularly "humane" and served as a pretext for the continuation of American nuclear weapons tests.

Starting in 1959, approximately, American voices were again heard, trying to prove in particular that only the United States, on the basis of "its economic strength," was in a position to produce "smaller nuclear weapons" in adequate quantities.

In 1960, the new "miracle weapon" was the "neutron bomb" which was to work primarily through the neutron component of instant nuclear radiation. In contrast to all the noise about the "clean bomb," it was advertised as being particularly effective precisely because it would act upon man above all through nuclear radiation while the blast wave and the flash [light radiation] would be of subordinate significance in terms of their destructive effect. Here is how the situation was described: "A revolutionary novel nuclear secret weapon has been developed by American scientists according to information supplied by former AEC member Murray. Murray at the same time emphatically came out in favor of lifting the atomic test ban which in effect made it impossible for the United States to win a new position of military and political strength. In the opinion of an American nuclear physicist, who does not wish his name to be known, the new weapon could be a 'neutron bomb' which releases lethal rays without causing any property damage."[24]

Starting in 1961, SAC conducted flights with nuclear bombs on board in the direction toward the Soviet Union and the socialist states. Among the four routes regularly flown, three run from the United States via Canada or Alaska or Greenland and the Polar region while the fourth one extends from the United States across the Middle Atlantic all the way to Spain.

In addition to the potential threat to the entire socialist camp, this kind of action is connected with a direct threat to the countries over which those planes fly. Between 1958 and 1968 alone there were 14 incidents involving nuclear bombs as well as various complications in SAC.

On 17 January 1966, a B-52 exploded during such a flight while refuelling in the air over the Spanish village of Palomares. At that time, three multi-phase nuclear bombs fell on farmland and the fourth one dropped 840 m deep into the Mediterranean.

On 21 January 1968, a B-52 crashed at Thule in the northwestern part of Greenland, hitting the permafrost surface; it exploded and the four nuclear bombs, with an intensity of 1 Mt, each, sank to a depth of 250 m.

Even if one keeps in mind that the multiple safeguard systems practically rule out any unintentional nuclear detonation in this kind of crash, there are still enough danger sources left.

For example, the decomposition of the plutonium fuse due to pressure and heat or the corrosion of the bomb casing cause a radioactive contamination of the terrain or the water. But this directly creates the danger of incorporating the alpha-active plutonium.[25]

England was the third country which, on 3 October 1952, conducted a nuclear fission weapons test on the Monte Bello Islands (northwestern part of Australia). The British nuclear weapons project had been launched in the autumn of 1951 under the code name "Tube Alloys Directorate" under the direction of Wallace Akers. Two other tests followed in 1953 at the Woomera Range in the southern Australian desert. The first test detonation involving a thermonuclear device was carried out on 15 May 1957 in the area of Christmas Island in the Pacific Ocean.

France was the fourth country on 13 February 1960 to detonate its first nuclear fission bomb at Reggane in the Sahara Desert. On 24 August 1968, it set off a thermonuclear device on Fangataufa Atoll in the Pacific Ocean.

Table 1.2. Data on the First 'A and H Bomb Test Detonations"[26]

	Staat	»A-Bombe« 2	Ort	3 Bemerkungen	»H-Bombe« 2	Ort	3 Bemerkungen
	USA	16.07.1945	Alamogordo (New Mexiko)	»Trinity-Test« Pu-239, 10 kt 4 Implosionsprinzip 5 Stahlturm (30 m)	01.11.1952	6 Elugelab (Stiller Ozean)	Test »Mike« D,T; 5 Mt 7 nicht transportabel
					28.02.1954	6 Bikini (Stiller Ozean)	LiD; 15 Mt 8 transportabel
9	UdSSR	29.08.1949		10 kt-Bereich Pu-239	12.08.1953		11 Mt-Bereich LiD 8 transportabel
	England	03.10.1952	Monte Bello 12 (Australien)	10 kt-Bereich	15.05.1957	13 Christmas-Insel 6 (Stiller Ozean)	11 Mt-Bereich
14	Frankreich	13.02.1960	Reggane 15 (Wüste Sahara)	60 ... 70 kt 16 Turm (100 m)	24.08.1968	Fangataufa 6 (Stiller Ozean)	2 Mt
17	VR China	16.10.1964	18 Provinz Sinkiang	U-235, 20 kt 16 Turm	17.06.1967	18 Provinz Sinkiang	3 Mt

Key: 1--Country; 2--Place; 3--Remarks; 4--Implosion principle; 5--Steel tower; 6--Pacific Ocean; 7--Not transportable; 8--Transportable; 9--USSR; 10--Kt range; 11--Mt range; 12--Australia; 13--Christmas Island; 14--France; 15--Sahara Desert; 16--Tower; 17--PRC; 18--Province of Sinkiang.

The PRC was the fifth and, for the time being, last country which on 16 October 1964 announced the first test detonation of a nuclear fission weapon. The test site was in the Province of Sinkiang. A thermonuclear device was exploded at the same site on 17 June 1967.

At this time we must estimate that a series of other imperialist states are working on the manufacture of nuclear weapons, are considering such steps, or are able to do so. Worldwide scientific and technical developments have produced a situation in which today there is practically no more "atomic secret" so that, in the final analysis, only the particular economic strength of a country will decide on the possibility of producing nuclear weapons.

Table 1.2 presents an overview of the first test detonations by the individual countries. In compiling this table and the following one, the problem was that the material available for analysis was not authentic in each case and that conflicting data are available in the literature on various events.

Overall, about 740 nuclear weapons detonations were triggered by the five nuclear powers between 1945 and 1970. We may estimate that this number is too low, rather than too high.

Regardless of this fact, Table 1.3 clearly shows that, even according to Western data, the Soviet Union confined the number of its tests to the militarily possible minimum.

On the basis of available data, we may furthermore estimate that the total equivalent of the detonation energy of all nuclear tests conducted so far is roughly on the order of magnitude of 500-550 Mt TNT.

Of that amount, about 400 Mt were used in about 100 tests in the Mt range in the atmosphere. The remaining 100-150 Mt must be credited to nuclear weapons detonations in the kt range and a few underground detonations in the Mt range. To be able to visualize these orders of magnitude, we may start with the assumption, by way of comparison, that the total intensity of the explosives (bombs, shells, etc.) employed during World War II by all belligerent countries was about 5 Mt.

The tests conducted so far were air, surface, water, and underwater detonations. Here it is particularly difficult to estimate the detonation intensities of underground detonations that were not officially announced. Until the year 1963, the share of underground and underwater detonations out of the total number of tests in the kt range was about 50 percent. Between 1964 and 1970 on the other hand underground detonations alone accounted for more than 90 percent of all tests conducted.

According to Western literature data, the hitherto strongest nuclear weapons detonation with 57 Mt was triggered by the Soviet Union on 30 October 1961 over Novaya Zemlya. The weakest test with a detonation intensity of only 0.0002 took place in Nevada on 30 October 1958. The hitherto highest detonation altitudes would seem to have been selected by the United States during the Argus series in August and September 1958 (three tests at 2 kt, each, at

an altitude of 480 km) and 9 July 1962 with a 1.2-Mt test at an altitude of 320 km over Johnston Island in the Pacific. The hitherto deepest known underground detonation with an intensity of 5 Mt at a depth of 2,000 m was triggered by the United States, in spite of worldwide protests, on 6 November 1971 on the Aleutian island of Amchitka.

Table 1.3. Compilation of Nuclear Weapons Detonations by the Individual Countries, 1945-1970[26]

		1945	1946	1947	1948	1949	1950	1951
	USA	3	2	–	3	–	–	17
	UdSSR	–	–	–	–	1	–	2
1	insgesamt:	3	2	–	3	1	–	19

		1952	1953	1954	1955	1956	1957	1958
	USA	9	11	6	15	14	28	66
	UdSSR	–	2	1	4	7	13	25
	England	1	2	–	–	6	7	5
1	insgesamt:	10	15	7	19	27	48	96

		1959	1960	1961	1962	1963	1964	1965
	USA	–	–	8	87	46	29	27
	UdSSR	–	–	30	38	3	5	8
	England	–	–	–	2	–	–	1
2	Frankreich	–	3	1	1	1	1	–
3	VR China	–	–	–	–	–	1	1
1	insgesamt:	–	3	39	128	50	36	37

		1966	1967	1968	1969	1970	1945–1970
	USA	9	33	32	27	27	499
	UdSSR	2	8	7	12	9	177
	England	–	–	–	–	–	24
2	Frankreich	5	4	5	–	8	29
3	VR China	3	2	1	2	1	11
1	insgesamt:	19	47	45	41	45	740

Key: 1--Total; 2--France; 3--PRC; UdSS--USSR.

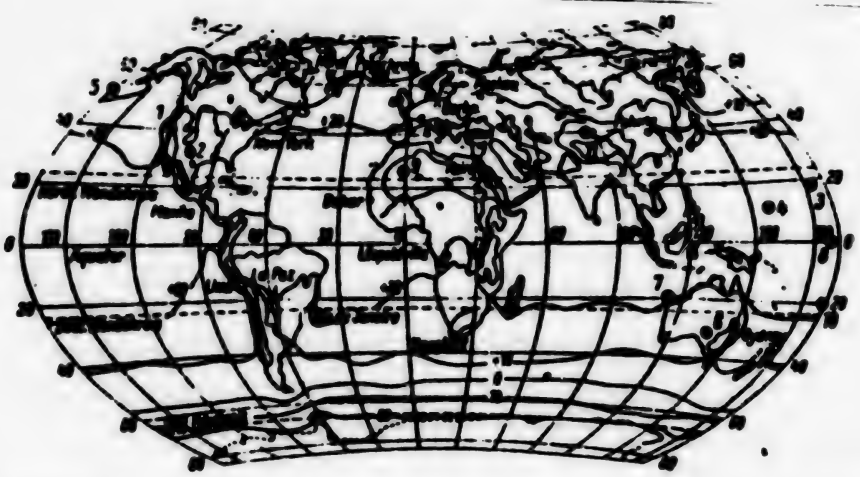


Figure 1.6. Geographic location of the most important nuclear weapons test sites of the United States, England, France, and the PRC.
Explanation for Figure 1.6

United States test sites: Nevada, U.S.A. (1), New Mexico, U.S.A. (2), Johnston Islands, south of Hawaii, Pacific Ocean (3), Bikini (Island), Marshall Islands, Pacific Ocean (4), Eniwetok (Island), Marshall Islands, Pacific Ocean (4), Amchitka (Island), Aleutians (5).

England's test sites: Woomera, southern Australia (6), Monte Bello (Islands), off the northwest coast of Australia (7), Christmas Island, Gilbert and Ellice Islands, Pacific Ocean (8).

France's test sites: Reggane, Central Sahara (9), Muruoa (Island), French Polynesia, Pacific Ocean (10), Fangataufa (Island), French Polynesia, Pacific Ocean (10).

PRC test sites: Province of Sinkiang, northwestern part of China (11).

Between 1945 and today we have two phases during which there were no nuclear weapons tests or during which these tests were or still are subjected to certain restrictions.

The first relative test suspension period, which was not based on any treaty agreement, lasted from the autumn of 1959 until September 1961. During that span of time, only France conducted nuclear weapons tests.

The second relative period of test suspensions began on 5 August 1963. On that date, the foreign ministers of the Soviet Union, the United States, and Great Britain signed the "Agreement on the Suspension of Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water" in Moscow. This step restricted the increasing "radioactive pollution" of the earth's atmosphere and the ocean water--but it only restricted it because France and the PRC did not sign that agreement. Another important step toward a reduction in international tensions was taken in 1968. After many years of constructive proposals by the Soviet Union and its efforts to achieve visible results in disarmament negotiations,

a proposal, submitted by the Soviet Union, was signed on 18 January 1968; the "Draft for a Treaty on the Nontransfer of Nuclear Weapons" was signed in Geneva by the 18-member disarmament committee of the UN.

The United States had submitted an identical treaty draft. On that basis, the 22nd UN General Assembly with an overwhelming majority on 12 June 1968 passed the nuclear weapons ban treaty which finally on 5 March 1970 entered into force after having been signed by more than a hundred countries, including of course the GDR. This created obligations which were binding under international law, obligations to refrain from any further dissemination of nuclear weapons and to stop the efforts of non-nuclear countries to gain access to nuclear weapons in any form whatsoever.

Negotiations then began in 1969 between the Soviet Union and the United States concerning the use of nuclear detonations for peaceful purposes; these negotiations are still going on as we prepare this chapter (August 1971).

The past history of nuclear weapons sketched here briefly, also confirms the observation of the International Conference of the Communist and Worker Parties of August 1969 in Moscow: "In view of the existing international balance of power, the nuclear weapons potential of the Soviet Union, and the possible consequences of a nuclear missile war, it is becoming increasingly difficult and dangerous for United States imperialism to bank on unleashing a new world war. Under these conditions, ruling American circles place special emphasis on local wars without abandoning the preparations for a world war. But the contrast between the policy of strength pursued by imperialism and its real possibilities is emerging ever more crassly."[27]

Review Questions

1.6. Into what fundamental stages can the past history of nuclear weapons be broken down?

1.7. Explain why the rapid development of Soviet nuclear weapons "was a matter of life and death for the defense of the Soviet Union."

1.8. What are the causes for the fact that the Soviet Union was able quickly to break the American nuclear weapons monopoly and then to achieve and maintain a lead in the development of nuclear missiles?

1.9. What international and military significance is attached to the Agreement on the Suspension of Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water, dated 5 August 1963, and the entry into force of the Nuclear Nonproliferation Treaty, dated 5 March 1970?

1.10. What is the connection between the need for constantly increasing the combat readiness of the NVA [National People's Army] and the struggle of the socialist countries, headed by the Soviet Union, for disarmament and a general ban on the use of nuclear weapons and other mass annihilation weapons?

1.3. Structure of Nuclear Fission Weapons

1.3.1. Nuclear Fission as Basis of Energy Release

1.3.1.1. Mass Defect and Nuclear Binding Energy[28]

Three types of elementary particles are involved in the immediate build-up of the atoms: Electrons, protons, and neutrons.

The atom itself consists of a relatively loose envelope of electrons and a very small nucleus with an extraordinarily high mass and charge density. The outside diameter of an atom is on the order of magnitude of 10^{-10} m, that of the nucleus is only 10^{-15} m. More than 99.9 percent of the total mass [weight] of an atom are concentrated in the nucleus. This means that the nucleus has a mass density of about 10^{17} kg m^{-3}.

Concerning the problems of nuclear energy release, we are only interested in the atomic nucleus. The energy amounts which can be released by changes in the nuclear structure can be 10^6 times higher than in chemical reactions.

In keeping with the theory of relativity, a particle also still has energy if its velocity is zero. This energy is called rest energy. The following relation then applies:

$$E = m \cdot c^2 \qquad (1.1)$$

It expresses the equivalence of energy and rest mass of a particle and, during the release of nuclear energy, supplies the connection between nuclear binding energy and mass defect. If, for example, we mathematically determine, from the individual masses, the mass of a helium atom ($^4_2$He; $2e^-$) on the basis of the values in Table 1.4 with the help of the following formula

$$m_A = Z \cdot m_p + N \cdot m_n + Z \cdot m_e \qquad (1.2)$$

Then, using the relative atomic weights, we get a value of $m_{He} = 4.0329$ ME. Compared to the real atomic weight of helium ($m = 4.0026$ ME), this value turns out to be 0.0303 ME too high.

Table 1.4. Brief Characteristics of Elementary Particles: Electron, Proton, and Neutron

1	Elementarteilchen	Elektron	Proton	Neutron
	Symbol	e^-	p	n
2	Ruhemasse, absolute kg	$9{,}1091 \cdot 10^{-31}$	$1{,}6725 \cdot 10^{-27}$	$1{,}6748 \cdot 10^{-27}$
3	Ruhemasse, relative ME[1]	0,000549	1,00727	1,00865
4	Ruhemasse, äquv. MeV/c²	0,5110	938,3	939,5
5	Elementarladung	−1	+1	0
6	mittlere freie Lebensdauer s	stabil 7	stabil 7	$1{,}0 \cdot 10^3$

Key: 1--Elementary particle; 2--Rest mass, absolute; 3--Rest mass, relative; 4--Rest mass, equivalent; 5--Elementary charge; 6--Average free lifetime; 7--Stable; (1) The relative atomic mass (rest mass) must not be confused with the mass number (mass number = proton number + neutron number); A = Z + N). Since 1961, the atomic mass unit has been defined as follows: 1 ME = 1/12 atomic mass of ${}^{12}_{6}C = 1.66043 \cdot 10^{-27}$ kg. The relative atomic mass accordingly is the ratio between the atomic mass of the corresponding atom (particle) and the atomic mass unit.

By way of explanation we might say that, during the formation of an atomic nucleus from free nucleons (protons and neutrons)—there develops a mass defect in whose place there comes an energy quantity which is equivalent according to Formula 1.1.

If we wanted to reverse this process, this energy would precisely once again have to be used for the separation of the nucleons. Looking at it this way nuclear energy is, by virtue of its essence, nuclear binding energy. Or, in other words, the more firmly a nucleon is bound to a nucleus as a result of a nuclear reaction, the greater will be the attendant mass defect and thus the released equivalent energy quantity.

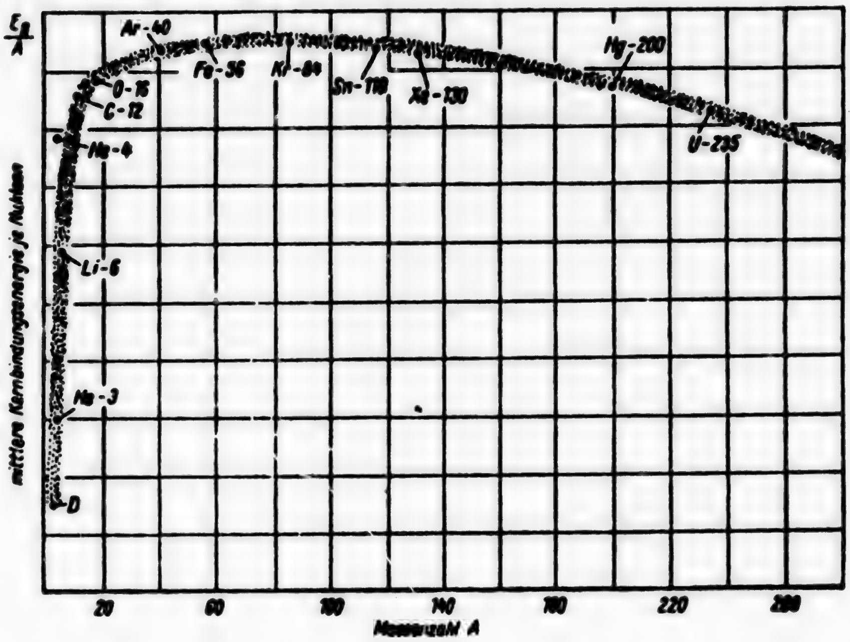
The reciprocal processes between atomic nuclei of varying structure or between those with different nuclear-active particles is considerably more complicated than the above example of the buildup of an atom or atomic nucleus from elementary particles. Such nuclear reactions can reveal both a positive and a negative energy balance. Basically, nuclear energy is released only if the mass of the nuclei or nuclear particles participating in the reaction meet the following inequality:

$$\sum m_{\text{original [parent] nuclei}} > \sum m_{\text{product}} \qquad (1.3)$$

We get initial conclusions as to the anticipated energy toning of a nuclear reaction if we illustrate the nuclear binding energy per nucleon as a function of the mass number; that is to say, in other words, if we divide the binding energy of any desired nucleus by the number of nucleons forming that nucleus.

In this case we can recognize that, up to a mass number of A = 60, the average nuclear binding energy per nucleon grows rapidly in terms of tendency and then again slowly decreases in the direction toward the heavy nuclei. Thus the average binding energy per nucleon is about 7 MeV for helium, 9 MeV (maximum) for iron, and 7.5 MeV for uranium; for the total spectrum of atomic nuclei, the value on the average is 8 Mev; this corresponds to a mass defect of 0.0089 ME. Nevertheless, especially in some light nuclei, there are considerable deviations from these average values. We can furthermore observe that the binding energy per nucleon for nuclei with an even mass number is greater than for the neighboring nuclei with an uneven mass number.

1



2

Figure 1.7. Average nuclear binding energy per nucleon as function of mass number A[29]. Key: 1--Average nuclear binding energy per nucleon; 2--Mass number A.

By way of summary, from what we have said here so far, we can derive two possibilities of nuclear energy procurement which were formulated already in Section 1.1., that is, the buildup of heavy nuclei from light nuclei and the fission of heavy nuclei into medium ones.

To continue our look at energy release based on nuclear fission (nuclear synthesis) it is not enough to illustrate the nuclear binding energy simply as a function of the mass number A because the latter after all consists of Z and N. Concerning the stability of a nucleus, the breakdown according to even or

odd proton and neutron numbers ((g, g)-, (g, u)-, (u, g)-, (u, u)- nuclei) provides further insight. It thus turns out that, in nature, nuclei of type (g, g) predominate (164 stable nuclides) while only four stable nuclides are known of nucleus type (u, u). In general we can say that the stability of the individual nucleus types decreases in the sequence mentioned above.

The stability of atomic nuclei is essentially determined by the number and the mixing ratio of protons and neutrons. For stable nuclei, we have $N = Z$, whereas for heavy nuclei we must have $N > Z$. Starting $Z \geq 84$ (Polonium), we only have unstable nuclides.

In the atomic nuclei which are made up of protons (positive elementary charge) and neutrons (no electrical charge), there must be different forces present which, in their totality, determine its stability or instability. In simplified form, this interconnection can be boiled down to the opposing action of the nuclear forces and the Coulomb forces.

Experience shows that there are strong binding forces also between the protons or neutrons among each other and between protons and neutrons as such. The magnitude of the binding forces decreases very rapidly as the distance increases; their practical range does not exceed $2 \cdot 10^{-15}$ m. These nuclear forces cause the formation of the nucleus from the nucleons. The nuclear forces act only between neighboring nucleons. This shows us that the "surface nucleons," which after all do not have any external neighbors, are bound more weakly than those deep in the nucleus. This assumption furthermore yields a certain surface tension and the explanation for the fact that most nuclei have a roughly spherical shape ("droplet model" or the atomic nucleus).

The nature of nuclear forces is still not fully understood. According to H. Yukawa, nuclear forces--similar to chemical binding forces--are considered exchange forces between the nucleons. The π-mesons or pions are considered as carriers of the nuclear force field. They can be exchanged between the nucleons.

The Coulomb forces, which work against the nuclear forces, result from the repelling effect of protons with the same charge. In comparison to them, they have a considerably greater range. Their magnitude decreases with the square of the distance between the protons. This is why each of the Z-protons acts upon the other (Z-1) protons.

While the nuclear forces increase only in proportion to Z, the Coulomb forces increase at Z^2. Because of the change in the ratio between protons and neutrons from 1:1 to about 1: 1.6--a change extending from the light to the heavy atomic nuclei--there is an increase in the average distance between the protons; but that cannot prevent the fact that, in the end, in case of very high nuclear charge numbers, the Coulomb forces will prevail which means that the nucleus becomes unstable. An atomic nucleus thus is stable so long as the following condition is met:

$$\Sigma F_{\text{nuclear forces}} > \Sigma F_{\text{Coulomb forces}} \qquad (1.4)$$

According to Bohr, the folowing inequality applies here:

$$\frac{Z^2}{A} < 45 \quad \text{or} \quad \frac{Z^2}{Z+N} < 45 \qquad (1.5)$$

1.3.1.2. Basic Condition for Nuclear Fission

Nuclear fission reactions can basically be triggered in a whole series of nucleus types. But only a certain number of heavy nuclei is suitable for use as fission materials (nuclear explosives). As far as we know now, for nuclear fission weapons, that would be the nuclides U-233, U-235, Pu-239, and possibly also Cf-249 and Cf-251. The nuclides U-238 and (Th-232) can furthermore be considered for use in multi-phase nuclear weapons.

The nuclei of these radionuclides are subjected to spontaneous nucleus decay or alpha decay. Compared to the half-life for the spontaneous nuclear decay ($T_s = 1.8 \cdot 10^{17}$ a for U-235) with those of alpha decay ($T_\alpha = 7.1 \cdot 10^8$ a for U-235) however shows that spontaneous fission is only very rare. From this we can also without further consideration draw the conclusion that a certain activation energy must be used in order to bring about forced nuclear fission. Its magnitude for nuclei with a mass number of $A \sim 230$ is less than 10 MeV.

The required activation energy can be supplied to the nucleus to be split by means of photons or due to the impact of particles (kinetic energy) and/or by their absorption (formation of an intermediate nucleus--binding energy). In the case of nuclear fission weapons, the neutrons are the sources of this activation energy.

The basic condition for nuclear fission in nuclear weapons consists in the fact that the sum of the binding energy E_B of the neutron absorbed in the intermediate nucleus and its kinetic energy E_{kin} is equal to or greater than the required activation energy E_W for the nuclide used as nuclear charge.

The following applies as a prerequisite for nuclear fission by means of neutrons:

$$E_{B(n)} + E_{kin(n)} \geq E_W \qquad (1.6)$$

Table 1.5 shows the activation energies for the most important nuclear explosives. We can see that, in the case of U-235 and Pu-239, the bonding energy of the neutron corresponds to the necessary activation energy or exceeds it. Something similar applies to U-233 which is not listed in the table. This is why these nuclides can already be split by thermal neutrons. (Thermal neutrons at 25° C have an average energy of $\bar{E}_n = 0.025$ MeV, at an average velocity of $\bar{v} = 2.2 \cdot 10^3$ m s^{-1}.) On the other hand, fast neutrons with an energy of $E_n \geq 1.5$ MeV are necessary for splitting U-238 (Th-232).

Table 1.5. Activation Energy E_W (Neutrons) in Terms of MeV for Some Heavy Nuclei[30]

Original nucleus	U-235	U-238	Pu-239
Intermediate nucleus	U-236	U-239	Pu-240
Activation energy	6.5	7.0	5.1
Neutron's binding energy	6.8	5.5	5.1
Neutron's kinetic energy	0	1.5	0

This difference exerts decisive influence on the possibilities of using both of these groups of nuclear explosives. We will go into greater detail on that later on.

With the help of the droplet model for the atomic nucleus it is possible clearly to illustrate the nuclear fission process. The supply of activation energy—which is connected with the absorption of the neutron and the formation of the intermediate nucleus—excites the fissile nucleus into pulsating oscillations. As a result of these oscillations, the previously spherical nucleus is deformed and it assumes a longitudinal, dumbbell-like shape. Two, spatially separated positive charging foci now begin to form, the Coulomb forces gain the upper hand, and finally lead to the splitting of the nucleus into two fragments (nuclear fragments). At the same time, two or three neutrons are released during this process. This is connected with the release of an energy amount that is equivalent to the developing mass defect and whose carriers [sources] are the nuclear fragments which move away from each other at fast speed, the neutrons, and the immediately emitted nuclear radiation (see Section 1.3.4.).

To conclude these elementary considerations, we might note that, even under the conditions given, not every absorption of a neutron need necessarily lead to nuclear fission. Instead, nuclear fission, like any other nuclear reaction, takes place only with a certain probability. Thus, we can match nuclear fission with a certain "action profile" which specifically depends on the nuclear structure and the energy of the neutrons.

If we look at the example illustrated in Figure 1.8, we find the following reaction probabilities:

During the absorption of thermal neutrons by U-235 nuclei, the probability of nuclear fission is 85 percent; in 13 percent of the cases, we get, on the average, neutron capture with the emission of a γ-quantum ((n, γ)-reaction) and in 2 percent of the cases we get elastic scatter ((n, n')-reaction).

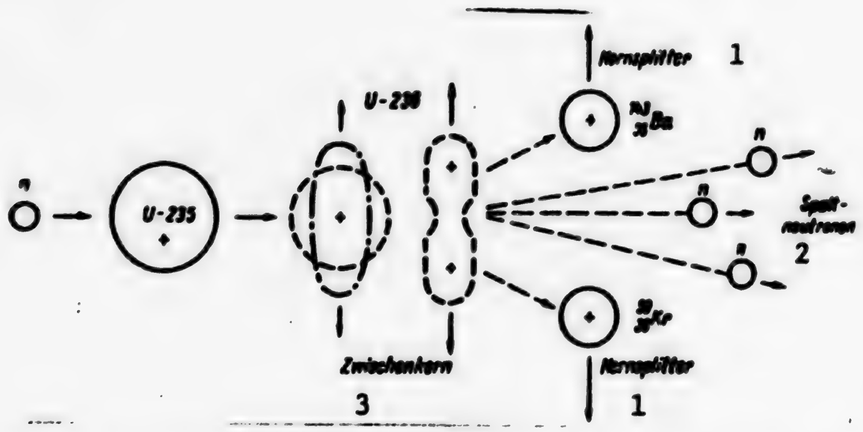


Figure 1.8. Basic diagram illustrating forces nuclear fission through neutron bombardment. Key: 1--Nuclear fragments; 2--Fission neutrons; 3--Intermediate [compound] nucleus.

1.3.1.3. Chain Reaction in Nuclear Explosive

The fission of the nuclear explosives mentioned is accompanied by four common characteristics:

For each nucleus split, we get an energy amount on the order of magnitude of about 200 MeV;

Two or three neutrons per fission event are released;

At the moment of fission, an average of 2 gamma quantums are emitted;

The nuclear fragments of the uranium or plutonium nucleus--the fission products--developing as a result of fission are radioactive.

The characteristic mentioned in second place--according to which secondary neutrons develop during nuclear fission--is particularly important. If the binding energy of these fission neutrons is enough in order, in turn, to bring about more nuclear fission, then a fission process, which has been initiated, can under certain conditions continue by itself and lead to a so-called chain reaction. This as we know applies to the nuclides U-233, U-235, and Pu-239.

The possibility of more nuclear fission due to secondary fission neutrons however does not yet lead to the development of such a chain reaction whose result is the release of nuclear energy through a detonation. For that, a series of other conditions must be met, that is to say, first of all, the chain reaction must continue via a number of fission cycles that will release enough energy and, besides, energy release must take place within a sufficiently short time interval.

The term "chain reaction" in the case of nuclear weapons means a series of exoergenic nuclear reactions which, after external initiation, will continue by themselves and which--due to the number of fission neutrons that keeps growing from generation to generation, from fission cycle to fission cycle--will

encompass more and more nuclei, will grow like an avalanche, and will thus release large quantities of energy within fractions of seconds in the form of a detonation.

As a basic prerequisite for the detonation-like release of nuclear energy, it emerges from the definition given that the number of fission neutrons must grow from generation to generation; that is to say, that the neutron multiplication factor k must be greater than unity.

The neutron multiplication factor k is defined as the quotient of the i/i-1 neutron generation.

A system, for which $k < 1$ applies, is termed subcritical. A reaction initiated from the outside will quickly die down again. When $k = 1$, a system is critical. The reaction takes place at steady speed and the energy release takes place in proportion to the reaction time (reactor).

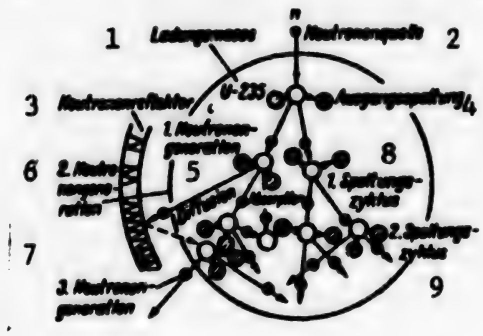


Figure 1.9. Basic diagram illustrating the course of the chain reaction in nuclear fission weapons. Key: 1—Charge mass; 2—Neutron source; 3—Neutron reflector; 4—Initial fission; 5—1st neutron generation; 6—2nd neutron generation; 7—3rd neutron generation; 8—1st fission cycle; 9—2nd fission cycle.

At the moment of ignition, $k > 1$ applies to the nuclear weapon.. It must then be considered a supercritical system.

$$k = \frac{i}{i - 1} > 1 \qquad (1.7)$$

Under specific conditions, the magnitude of the multiplication factor k depends on the number of neutrons released per fission event, the ratio between the nuclear fission cross-section and the cross-section for other processes not leading to the release of new neutrons, the type, size, and shape of the particular fission material, as well as some other marginal conditions.

If all of the neutrons released during nuclear fission were to cause further fission, then the neutron multiplication factor could attain a maximum value of about $k = 2.5$. This value however cannot be achieved in nuclear weapons. The

most important reasons for this are that a part of the neutrons is diffused out of the nuclear fission zone while another part is absorbed by the fission product, the admixtures, etc.

Basically we must observe that the course of a chain reaction is always tied to a minimum quantity of nuclear explosives.

To bring about a chain reaction when $k > 1$, we need a certain quantity of fission material. This minimum quantity is called the critical mass.

The critical mass is not a fixed absolute magnitude. Instead, it depends both on the nuclear-physics parameters of the particular nuclear explosive and on the design and structure of the nuclear weapon itself. If we start with a spherical charge arrangement, then the size of the critical mass is determined by the effect cross-section, the neutron multiplication factor, and the average free path length of the neutrons. The action cross-section however depends on the velocity (energy) of the fission neutrons. The free path length of the neutrons again is determined by the nuclear fission cross-section and the number of fissile nuclei per charge mass volume unit. This is why the diameter of the nuclear charge in the supercritical state must be considerably larger than the average free path length of the neutron. Further comments on this problem complex can be found in the following chapter.

1.3.2. Basic Elements of Nuclear Fission Weapons

The basic elements of each nuclear fission weapon are the nuclear charge, the detonation device, and the casing.

Without going into detail, we will explain its essential structure and basic function below.

1.3.2.1. Nuclear Charge

The most important characteristic magnitudes for the nuclear charge are the nuclear explosive used, the charge mass, and the charge volume. The tables below present some values in this connection.

Table 1.6. Brief Description of Nuclear Explosives

1	Nuklid	$^{233}_{92}U$	$^{235}_{92}U$	$^{239}_{94}Pu$
2	Kernmasse, absolute kg	$3{,}8694 \cdot 10^{-25}$	$3{,}9027 \cdot 10^{-25}$	$3{,}9693 \cdot 10^{-25}$
3	Kernmasse, relative ME	233,03784	235,04232	239,05053
4	kritische Masse kg¹)	7,5	22,8	5,6
5	Spaltneutronen je Kern	2,5	2,4	2,9
6	Dichte $g\,cm^{-3}$	18,7	19,0	19,6
7	T, Alphazerfall a	$1{,}6 \cdot 10^{5}$	$7{,}1 \cdot 10^{8}$	$2{,}4 \cdot 10^{4}$
8	T, spontane Spaltung a	$3{,}0 \cdot 10^{17}$	$1{,}8 \cdot 10^{17}$	$5{,}5 \cdot 10^{15}$
9	rel. Häufigkeit des Isotops bzw. Brutstoff	Th-232²)	0,71 %	U-238³)

Key: 1—Nuclide; 2—Nuclear mass, absolute; 3—Nuclear mass, relative; 4—Critical mass; 5—Fission neutrons per nucleus; 6—Density; 7—T, alpha decay; 8—T, spontaneous fission; 9—Relative frequency of isotope or breeder substance.

(1) The data pertain to a system made up of metallic U-233, U-235, or Pu-239 with a standard water reflector. For nuclear fission weapons, the values are considerably lower.

(2) The production of U-233 takes place in breeder reactors from Th-232 according to the following scheme:

$$^{232}_{90}Th\,(n,\gamma)\,^{233}_{90}Th \xrightarrow[\beta^-]{23{,}5\ min} {}^{233}_{91}Pa \xrightarrow[\beta^-]{27{,}4\ d} {}^{233}_{92}U$$

(3) The production of Th-239 from U-238 is based on the following scheme:

$$^{238}_{92}U\,(n,\gamma)\,^{239}_{92}U \xrightarrow[\beta^-]{2{,}3\ d} {}^{239}_{93}Np \xrightarrow[\beta^-]{23\ min} {}^{239}_{94}Pu$$

The detonation energy of 1 kg TNT corresponds roughly to an energy amount of 1,000 kcal. If we therefore insert q in terms of kt in the following expression for the detonation equivalent of a nuclear fission weapon, then we get the following for the total energy released as a function of the detonation intensity:

$$E_{ges} = 10^{9} \cdot q \quad \text{kcal} \qquad (1.8)$$

Considering the corresponding conversion factors for the energy units, it therefore follows furthermore that:

$$E_{Det} = 4.187 \cdot 10^{19} \cdot q \quad \text{erg} \tag{1.9}$$

and

$$E_{Det} = 2.614 \cdot 10^{25} \cdot q \quad \text{MeV} \tag{1.10}$$

Assuming that an energy amount of 200 MeV is released per nucleus split, we can compute, from the numerical value Equation 1.10, the number of nuclear fission acts z necessary to release the detonation intensity q as follows:

$$z = \frac{E_{Det}}{E_{sp}} = \frac{2.614 \cdot 10^{25} \cdot q}{200}$$

$$z = 1.307 \cdot 10^{23} \cdot q \quad \text{nuclei.} \tag{1.11}$$

By inserting the Avogadro constant N_A into this equation ($N_A = 6.02252 \cdot 10^{26}$ $1/(A\ kg)$)[31], it follows, for the size of the necessary charge mass Q' in kg, if the minor differences in the sizes of the kg atoms A kg of U-233, U-235, or Pu-239 are neglected, that:

$$Q' = \frac{z}{N_A} = \frac{1.307 \cdot 10^{23} \cdot q}{\frac{6.023 \cdot 10^{26}}{235}} = \frac{1.307 \cdot 10^{23} \cdot q \cdot 235}{6.023 \cdot 10^{26}}$$

$$Q' \approx 0.05 \cdot q \quad \text{kg} \tag{1.12}$$

The complete fission of the nuclei of about 500 g of the particular nuclear explosive is thus necessary to release the detonation energy of 1 kt TNT.

Assuming that the nuclear fission of the charge mass of a nuclear weapon always takes place only at a certain efficiency η, the practical mass Q of the nuclear charge must always be considerably larger than Q'. The following then applies as a function of η:

$$Q \approx \frac{0.05 \cdot q}{\eta} \quad \text{kg} \tag{1.12}$$

From this it follows for the magnitude of the particular charge volume V_L that:

$$V_L = \frac{Q}{\varrho} \cdot 10^3 \quad \text{cm}^3 \quad \left| \frac{Q}{\text{kg}} \middle| \frac{\varrho}{\text{g cm}^{-3}} \right| \tag{1.13}$$

The values for the density ρ can be seen in Table 1.6.

Regardless of the fact that the size of the nuclear charge of a nuclear fission weapon must correspond to the particular detonation intensity, it must in every

case be greater than the critical mass of the nuclear explosive used. A detonation is impossible under other conditions.

Table 1.7. Reference Values for Important Characteristic Magnitudes of Nuclear Fission Weapons (1)

	1 Detonationsstärke				
	5 kt	10 kt	20 kt	50 kt	100 kt
q/kcal	$5 \cdot 10^{9}$	10^{10}	$2 \cdot 10^{10}$	$3 \cdot 10^{10}$	10^{11}
q/MeV	$1{,}3 \cdot 10^{26}$	$2{,}6 \cdot 10^{26}$	$5{,}2 \cdot 10^{26}$	$1{,}3 \cdot 10^{27}$	$2{,}6 \cdot 10^{27}$
Q/kg	1,25	2,5	5,0	12,5	25
V_L/cm^3	65	130	260	650	1300
r_L/cm	2,5	3,1	4,0	5,4	6,8

Key: 1—Detonation intensity; (1) The data in this table were calculated with the help of the formulas given above, assuming an efficiency of $\eta = 0.2$ of nuclear fission. The value r_L in the last line gives us the theoretical radius of the supercritical charge arrangement.

On the basis of the nuclear physics considerations presented in Section 1.3.1.3 concerning the critical mass we can say by way of generalization that its particular specific size depends on the following:

The type of nuclear explosive,

The shape of the nuclear charge,

The density of the nuclear explosive,

Its purity, as well as,

The construction of the detonation mechanism and the casing.

Other things being equal, the smallest critical mass undoubtedly is attained through a spherical arrangement of the fission material because we then get the best ratio between the volume and the surface of the nuclear charge.

The larger the surface of the active zone in relation to the charge mass, the bigger will be the neutron losses due to diffusion. If therefore the charge volume in terms of its shape deviates heavily from that of a sphere, then the size of the critical mass increases greatly and the neutron losses finally become so heavy that, regardless of the quantity of available nuclear explosive, a detonation becomes impossible. If we have a cylindrical nuclear charge of Pu-239, that, for example, will be the case if the radius of the cylinder is smaller than 2.15 cm (prerequisites same as in Table 1.6).[32] In the combination of subcritical charge parts to make up a supercritical overall system, the ratio between the volume and the surface of the nuclear charge is also changed

necessarily. For example, if, in a certain design of a nuclear fission weapon, we have 10 kg U-235 in the shape of two separate spheres, then their surface is about 240 cm^2, each; after their combination, the total surface on the other hand is only about 310 cm^2.

Changes in the density of the nuclear explosive likewise lead to an immediate change in the overall system's critical parameters. The book entitled "Kerndetonationen" [Nuclear Detonations] already points out that, in the nuclear fission bomb dropped on Nagasaki, by the United States, the critical mass was brought about by means of an implosion.[33] Here, a thin-walled hollow sphere made of Pu-239 was reportedly surrounded by an explosive mantle whose detonation energy upon ignition brought about the supercritical state due to the deformation and compression of the plutonium charge.

Assuming that the density of the nuclear charge and the density of the reflector change in proportion--the function of the neutron reflector will be covered later on--we can say that an increase in the density by the factor a brings about a reduction of the linear dimensions of the critical mass by $1/a$, of the corresponding volume by $1/a^3$, and of the critical mass itself by $1/a^2$.

In other words, this means that the magnitude of the critical mass is inversely proportional to the square of the density. At a pressure of 1 million kp cm^{-2}, the density of the nuclear charge would thus be doubled while the size of the critical mass would still be 1/4 of the initial value.

The purity of a nuclear explosive also exerts essential influence on the magnitude of the critical mass. Here, the particular share of foreign atoms depends especially on the specific production methods (separation methods) used for the fission materials and this must also be considered from economic viewpoints.

For example, a nuclear charge of U-235 will always contain a certain percentage of U-238. U-238 however can be considered an absorber for thermal neutrons. Depending upon the share of foreign isotopes, the fission neutrons thus are subjected either to fission capture or to radiation capture (n, γ). These absorbed neutrons do not participate in the further chain reaction. This causes a deterioration in the neutron multiplication factor and the size of the required critical mass will necessarily increase.

The situation is similar in the case of U-233 and Pu-239. The fission products as well as other construction materials used in the nuclear weapon can also act as neutron absorbers. The problem complex of the neutron reflector and its decisive significance to the size of the critical mass and the efficiency of nuclear explosive utilization will be discussed in connection with the description of the function of the casing of a nuclear fission weapon in Section 1.3.2.3. At this point we might merely remark that, in the case of nuclear fission weapons, it is possible, due to a corresponding construction of the actual reaction compartment, again to throw a part of the neutrons coming out of the active zone back into it and thus to influence the neutron multiplication factor.

1.3.2.2. Detonation Device

The detonation device of a nuclear weapon comprises the ignition mechanism, including the safety system, devices for the fast materialization of the supercritical charge arrangement, as well as additional elements which are necessary for the materialization of the chain reaction and (as a rule) for the maximum utilization of the nuclear charge; in other words, a high efficiency.

The ignition process essentially contains the removal of the last safety device after separation from the delivery means or, upon reaching the target area, the ignition of the initial explosive, the combination of the individual charge parts or the production, elsewhere, of the supercritical mass and the triggering of the chain reaction. Ignition, for example, can be triggered by impact fuses, time fuses, air-pressure fuses (built-in barometer), proximity fuses (radar fuses), or also influence fuses (using the heat radiation or magnetic field influencing of the target). Until the moment of ignition, the nuclear charge is in the subcritical state and is secured several times over and independently of the other components against unintentional detonation.

Considering the mentioned factors which determine or essentially influence the size of the critical mass in a specific charge arrangement, we get several ways to bring about the supercritical state of the nuclear charge and thus to trigger the internal detonation process.

The first basic way consists in the fact that the total charge is so broken down into charge components and placed in the weapon that the mass of each component charge is smaller than the critical mass of the nuclear explosive. But this means that the number of necessary component charges keeps growing as the detonation intensity increases. This cannot be done in an unlimited fashion for certain reasons. If, for example, the size of the critical charge for U-235 increases to about 6 kg (with reflector), then it would be necessary to subdivide the nuclear charge of a nuclear fission weapon with a detonation intensity of $q = 100$ kt into more than four parts. The biggest difficulty now obviously would not be this subdivision process but rather the simultaneous combination--coordinated to 1/1,000,000 sec, of the individual charge parts to make up the supercritical overall arrangement. If there is even the slightest delay in a charge part, this produces severe effects on the entire course of the detonation and the magnitude of the released detonation energy. This is why one may assume that this principle is used only in conjunction with small detonation intensities.

The second basic way consists in the fact that the supercritical charge mass is brought about as a result of an implosion. In this case, the entire nuclear charge is placed in the weapon in a compact fashion so that there are no mobile individual charge parts. The overall charge nevertheless is in the subcritical state and this is due to the fact that the nuclear explosive is arranged in the shape of a thin-walled sphere or is present as a loose, highly porous material. The nuclear charge itself is surrounded by a neutron reflector which, in turn, again is surrounded all over by the initial explosive. At the moment of ignition, the reflector and the nuclear charge are compressed extremely powerfully and as a result of that the total system becomes supercritical and the nuclear weapon explodes.

In addition to these possibilities of switching the nuclear weapon from the subcritical to the supercritical state mentioned here, others are conceivable which however are of minor significance in understanding the overall problem complex and which therefore will not be further described here.

A decisive prerequisite for a high degree of nuclear explosive utilization among other things consists in the fact that, at the moment of ignition, the supercritical charge state is in fact brought about instantly and that the process of energy release takes place in the shortest possible time interval.

This simply springs from the fact that the weapon is broken down very quickly as a result of the detonation although about 90 percent of the total detonation energy comes only from the last fission cycle of the chain reaction.

Table 1.8 presents an overview of the number of fission cycles n, the total duration of the course of the chain reaction t, as well as the time span t_1 during which about 90 percent of the detonation energy are released. The data in the table were calculated for a multiplication factor of k = 2 and an average time duration of 10^{-8} sec between two fission events.

Table 1.8. Reference Values to Describe the Course of the Chain Reaction

	1 Detonationsstärke				
	5 kt	10 kt	20 kt	50 kt	100 kt
n	79	80	81	83	84
t/s	$7{,}9 \cdot 10^{-7}$	$8{,}0 \cdot 10^{-}$[illegible]	$8{,}1 \cdot 10^{-7}$	$8{,}3 \cdot 10^{-7}$	$8{,}4 \cdot 10^{-7}$
t_1/s	$5{,}1 \cdot 10^{-8}$	$6{,}5 \cdot 10^{-8}$	$8{,}1 \cdot 10^{-8}$	$1{,}1 \cdot 10^{-7}$	$1{,}4 \cdot 10^{-7}$

1. Key: 1—Detonation intensity.

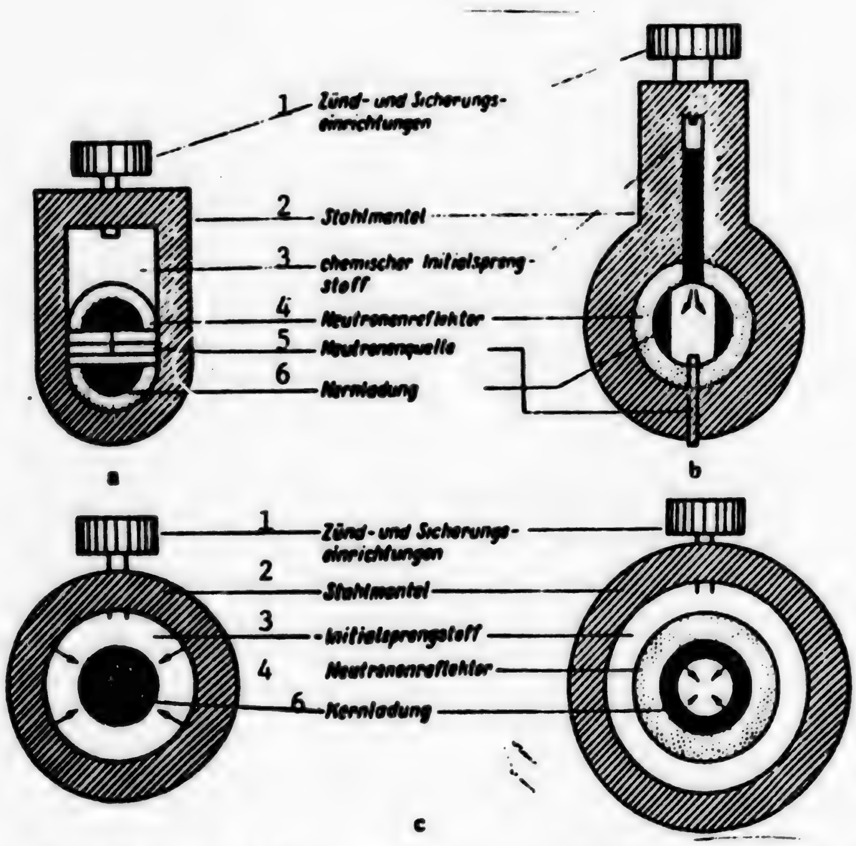


Figure 1.10. Greatly simplified illustration of the structure of nuclear fission weapons. a--Combination of two charge parts; b--Combination and deformation of charge parts; c--Implosion. Key: 1--Ignition and safety mechanisms; 2--Steel casing; 3--Chemical initial explosive; 4--Neutron reflector; 5--Neutron source; 6--Neutron charge.

Regardless of the relative information provided by these figures, they do make it clear how small the differences for n and t are for the individual detonation intensities. This is why they have an extraordinarily powerful effect on the released summary detonation energy already in case of the slightest time shifts in the course of the chain reaction. During each nuclear weapons detonation we would therefore expect a more or less strong deviation from the standard value given for the detonation intensity.

The smaller the real value of the neutron multiplication factor k is, the greater will be the required reaction time to release the energy of a certain detonation intensity k and the longer will the charge mass of the nuclear weapon have to be held together. In comparison to the values given in the tables we thus get the following: for $q = 100$ kt and $k = 1.2$; for $n = 310$, $t = 3.1 \cdot 10^{-6}$ sec, and $t_1 = 5.2 \cdot 10^{-7}$ sec.

In general, the total nuclear reaction time is as follows:

$$t = n \cdot t_m \text{ s} \qquad (1.14)$$

n = Number of fission cycles taking place
t_m = Average time between two fissions ($t_m = 10^{-8}$ s)

To produce a detonation energy of q kt, as we showed, it is necessary to split $z = 1.307 \times 10^{23} \cdot q$ nuclei.

The following furthermore applies in case of a neutron multiplication factor k = 2 and an initial value of $a_1 = 1$ for the chain reaction (that is to say, no separate neutron source, see below):

$$z = \frac{k^n - 1}{k - 1} = 2^n - 1 \approx 2^n \quad (1.15)$$

It follows from this that:

$$z = 2^n = 1{,}307 \cdot 10^{23} \cdot q$$

and dissolving for n, we get the corresponding number of fission cycles as follows:

$$n = 76{,}81 + 3{,}32 \lg q \quad (1.16)$$

According to Formula 1.14 we get the chain reaction time as follows from this:

$$t = (76{,}81 + 3{,}32 \lg q) \cdot 10^{-8} \text{ s} \quad (1.17)$$

Similar considerations give us approximately the following relationship for the determination of the t_1 value:

$$t_1 \approx 3{,}0 \cdot 10^{-8} \cdot q^{1/3} \text{ s} \quad (1.18)$$

An essential element in the detonation device of nuclear fission weapons consists of the neutron sources. They are inserted into the nuclear weapon prior to employment and can have two basic functions.

First of all, they are intended to trigger the chain reaction at the moment of ignition in an instantaneous fashion; besides, they can increase the efficiency of nuclear explosive utilization. In the last case, their purpose is to reduce the number of fission cycles required for the release of a certain detonation energy. To perform this function, the neutron sources used, however, must be highly active.

If, for example, we start with a neutron source with a yield of 10^{10} neutrons per second, then the total chain reaction time when q = 100 kt and k = 2 will be reduced by about $\Delta t = 8 \cdot 10^{-8}$ sec and, when k = 1.2, it will even be reduced by $\Delta t = 2.7 \cdot 10^{-7}$ sec. This, calculating roughly, is a decrease in the particular reaction times by about 10 percent.

As an example of a neutron source we might mention a mixture of beryllium and radium bromide powder. The neutron release then takes place according to the reaction equation:

$$^{9}_{4}Be(\alpha, n)\,^{12}_{6}C$$

At a ratio of 3-5 g beryllium per 1 g of pure radium, such a source--if the radium is in balance with its decay products--will supply about 10^7 neutrons per second for each gram of radium.

1.3.2.3. Casing

The casing of the nuclear fission weapon generally performs three independent functions:

Reception of nuclear charge and of individual elements of detonation device;

Guaranteeing the required reaction time for energy release due to a delay in the breakdown of the weapon;

Reduction in the critical dimensions of the charge mass and better utilization of nuclear explosive through its neutron-reflecting effect.

Comparisons between the mass of the nuclear charge and the total mass of a nuclear fission weapon show that they are roughly in a ratio of 1:100. This tells us that nuclear fission weapons must have a thick-walled casing made of heavy material.

According to the data in Table 1.8, the reaction times for the chain reaction are on the order of magnitude of 10^{-6} sec. During that time, the casing must prevent the premature explosion of the charge mass and thus the immediate discontinuation of the chain reaction.

Here we can note that, considering the extremely high pressure values, such as they appear immediately after ignition, the casing's ability for temporarily maintaining the chain reaction depends only on the size of its mass. The delay in the breakdown of a nuclear weapon will thus be all the longer, the more inert the casing happens to be. Here, the type of material—apart from its density--plays a subordinate role.

It has already been mentioned that neutron losses arise due to absorption and diffusion during the chain reaction. The neutron losses caused by diffusion can be considerably reduced by designing the nuclear fission weapon's casing as a neutron reflector. Such a reflector will throw a part of the neutrons coming out of the reaction zone back into it and therefore leads to a decisive reduction in the critical mass of the fissile system and thus to greater utilization of the nuclear charge.

Specifically, the effectiveness of a neutron reflector depends on the material used and its thickness. Using the same material, the effect of the reflector increases in proportion to its thicknees up to a certain boundary value.

For a standard water reflector, the optimum figures are at 6 cm. For graphite, they are 50 cm and for concrete they are about 30 cm. In the case of nuclear fission weapons, the neutron reflector must directly and firmly enclose the supercritical charge mass because even the slightest intervals will severely reduce its effectiveness. This is why the implosion principle must be considered to be very favorable.

The use of neutron reflectors is particularly important in the case of nuclear weapons with smaller detonation intensity because the neutron losses here otherwise would be very heavy.

Steel, beryllium, beryllium oxides, graphite, and their mixtures are considered particularly as neutron reflectors for nuclear fission weapons. Their effectiveness will be explained with the help of some numerical examples.

In case of a spherical arrangement, the size of the critical mass for U-235, enriched to 93.5 percent, without reflector is 52 kg. Using a water reflector, we can reduce this value to 22.8 kg and if we have a reflector consisting of beryllium oxide, it can be reduced to 8.9 kg.

For almost pure Pu-239 and a spherical arrangement of the fission materials, the critical mass is around 10 kg without reflector. A beryllium reflector with a thickness of 8 cm reduces the critical mass of Pu-239 to 4.7 kg and a reflector with a thickness of 32 cm will reduce it to 2.5 kg.

By way of summary, concerning the basic approach to the fundamental structure of nuclear fission weapons in this section, we can say that it has been possible successfully through design and other measures constantly to reduce the required size of the critical mass, to increase the efficiency, and considerably to reduce the total mass of nuclear weapons as well as their dimensions. These were decisive prerequisites for the development of nuclear warheads, for example; for various artillery systems and nuclear mines.

The nuclear bombs used against Hiroshima and Nagasaki, with a detonation intensity of 20 kt TNT, each, with a nuclear charge of only 50 kg and an efficiency of 2 percent, had a total mass of about 5 t, each. At this time we may figure that a nuclear weapon of equivalent strength will have a nuclear charge of about 5 kg with an efficiency of 20 percent and a total mass of 0.3-0.5 t.

1.3.3. Nuclear Weapons of Smaller Detonation Intensity

To make nuclear weapons with smaller detonation intensity--whose equivalents partly are extremely close to the detonation intensities of conventional ammunition--there are theoretically two possibilities. One way leads via the so-called "subcaliber nuclear weapons," while the other one leads via the utilization of nuclear explosives with a very small critical mass.

During the complete fission of all atomic nuclei in a plutonium charge of 1 kg, we get a detonation energy amount of 20 kt. It follows from this that, for every kt TNT equivalent of a nuclear weapon, we only need the complete fission of 50 g plutonium. If we assume that we can figure on an average efficiency of

20 percent, then this would be tantamount to a total nuclear explosive quantity of 250 g per kt of detonation energy. It followed from the explanations given in Section 1.3.1.3. concerning the critical mass and the numerical examples given in the following sections that, to have a chain reaction, we need a critical mass whose magnitude for Pu-239 is at least 1 kg even under the most favorable conditions. But this means that the smallest detonation intensity which can be achieved on this basis--assuming the maximum utilization of the nuclear explosive--would be about 5 kt TNT.

Basically, the reduction of the efficiency of a nuclear fission weapon does not present any great difficulties. Here we only have to do the opposite, in design terms, of what we want to achieve for the maximum utilization of the nuclear charge at "normal" detonation intensities.

First of all it is possible deliberately to slow down the process of bringing about the supercritical charge arrangement at the moment of ignition. This can be achieved among other things by dropping the principle of implosion and approaching the charge parts to each other relatively slowly.

Besides, the chain reaction can be broken off in that we counter the rapid decomposition of the nuclear charge by means of a thin casing for the nuclear weapon with only minimum inertia.

Another possibility consists in the use of neutron absorbers which lead to a reduction in the size of the neutron multiplication factor k and thus the efficiency.

All of the ways sketched here--which in practice naturally have further, considerably more complicated consequences--in the final analysis boil down to the fact that, considering a magnitude of the critical mass which we cannot go below, the chain reaction is broken off prematurely and that the detonation equivalent therefore is deliberately kept small.

Subcaliber nuclear weapons are nuclear weapons whose efficiency is below the maximum possible efficiency using the same quantity of nuclear explosive.

In this way, we can achieve nuclear fission weapons with detonatio ntensities between several hundreds of tons of TNT and several kilotons of TN h a justifiable effort.[34]

A decisive prerequisite for the mass production of nuclear fission weapons with small and very small detonation intensities on the basis of relatively poor utilization of the particular nuclear charges was the presence of sufficient supplies of fissile materials.

This is why subcaliber nuclear weapons--whose construction was basically possible from the very beginning--did not appear until the early 1960's. At that time the armament of the armies already included nuclear weapons systems for the most varied purposes with a broad scale of detonation intensities. On top of that we have the fact that methods for obtaining and processing nuclear explosives had by that time matured quite extensively.

The production of nuclear weapons on the basis of the "subcaliber principle" does not only have an uneconomical side. There is also a series of other aspects which make it appear impractical to use this method even for extremely small detonation equivalents.

According to American data, for example, in a series of tests in the autumn of 1957, nuclear charges with detonation intensities of only 0.001 kt, 0.006 kt, and 0.036 kt were tested. With such low detonation intensities, it is very difficult to determine the efficiency from the design angle. In other words, this means that, as the detonation intensity becomes smaller, the possible deviations from the standard value given will become bigger all the time. It must furthermore be kept in mind that, looking at subcaliber nuclear weapons, the share of unsplit nuclear charges out of the total quantity of radioactive detonation products is very high. But it so happens that Pu-239 is not only a very long-lived alpha-active radionuclide but moreover is biologically very dangerous and chemically highly toxic.

So far we have had only unofficial publications on the use of fission materials with a critical mass magnitude which is far below that of Pu-239, for the production of nuclear weapons with extremely low detonation intensities. Accordingly, Californium, for example, is supposed to be useful for these purposes, specifically, the isotopes Cf-294 and Cf-251.

The critical mass is given here only at 1.5 g without reference to a specific nuclide. Using this value as basis, this would mean that, figuring on a maximum efficiency of 20 percent and a minimum efficiency of only 0.1 percent, one could achieve detonation intensities in the range of 0.06-0.00003 kt.

The resultant possible weapons-engineering aspects are quite obvious. But they would be of basic military significance only if the suitable Californium isotopes could be produced in large quantities with a justifiable economic effort. This however obviously is not the case.[35]

1.3.4. Energy Release during Detonation of Nuclear Fission Weapon

The internal detonation process in a nuclear fission weapon starts with the triggering of the chain reaction due to the conversion of the nuclear charge from the subcritical to the supercritical state. The reaction time is extremely short and, as we said before, is something like 10^{-6} sec.

In our comments on the nuclear charge of a nuclear fission weapon in Section 1.3.2.1., we assumed--in deriving Formula 1.11--that, on the average, for each nucleus split, an energy amount of 200 Mev is released. This can be shown in detail if we compare the masses present before and after nuclear fission and if we compute the energy belonging to the resultant mass defect.

Among the many possibilities for nuc[illegible] fission we might make reference here to the example illustrated in Figure [illegible] below.

Table 1.9. Example of Energy Balance during Fission of U-235 Nucleus

	Mass number	Relative nuclear mass ME
(1) Sum of nuclear masses prior to fission		
(1.1) Parent nucleus U-235	235	235.0432
(1.2) Triggering neutron	1	1.00865
(1.3) Σ (1.1) + (1.2)	236	236.05097
(2) Sum of nuclear masses after fission, after completion of radioactive decay(1)		
(2.1) neodymium nucleus formed, $^{143}_{60}Nd$	143	142.90862
(2.2) zirconium nucleus formed, $^{90}_{40}Zr$	90	89.90430
(2.3) 3 fission neutrons, 3 $^{1}_{0}n$	3	3.02595
(2.4) Σ (2.1) to (2.3)	236	235.83887

(3) Size of mass defect: (1.3) to (2.4) $\Delta m = 0.2121$
Because 1 ME corresponds to an energy of 931 MeV, it follows for Δm:
$E_{s_p} = 0.2121 \cdot 931$ MeV = 197 MeV(2)

(1) The original nucleus fragments $^{143}_{56}Ba$ and $^{90}_{36}Kr$ are converted into $^{143}_{60}Nd$ or $^{90}_{40}Zr$ as a result of four successive beta decay processes. The balance given in the table thus contains the energy released as a result of the radioactive decay of the nuclear fragments.
(2) In case of a different type of nuclear fission of U-235, the energy is partly above this value so that the 200 MeV figured as mean value relate to the entire fission product mixture.

The nuclear energy of 200 Mev per split nucleus is directly distributed over the moment of detonation and the following interval of radioactive decay of the fission products. It appears here in various energy forms. Table 1.10 presents an overview.

Table 1.10. Energy Distribution during Fission of Heavy Nuclei

Energy form	Energy quantity MeV	%
In the process of nuclear fission		
kinetic energy of fission products	165 ± 5	82.5
kinetic energy of neutrons	5 ± 0.5	2.5
energy of gamma radiation	7 ± 1	3.5
In the course of radioactive decay of fission products		
energy of beta radiation	7 ± 1	3.5
energy of neutrinos	10	5.0
energy of gamma radiation	6 ± 1	3.0
Total energy per fission	200 ± 6	100

The biggest part of the detonation energy is converted into thermal energy. This heats the entire charge mass to extremely high temperatures. The developing positive nuclear fragments repel each other and move away from each other at fast speed. During collision with other nuclei in the charge, their kinetic energy is primarily converted mainly into heat. The unsplit part of the nuclear charge and the fission products formed are heavily ionized due to the gamma quantums and neutrons released during nuclear fission and are in fact stripped of their electron envelope. The subsequent recombinations lead to the emission of light radiation and x-rays whose energy likewise is consumed to the extent of more than 90 percent to heat the reaction zone.

In this way, very high energy concentrations are achieved during detonation.

According to Formula 1.10., the equivalent energy amount of $2.614\cdot 10^{25}$ Mev corresponds to a detonation intensity of 1 kt. For this we need about 50 g nuclear explosive (1.12). Assuming a density of 19 g cm^{-3}, we can calculate the corresponding charge volume at about 2.6 cm^3. For an efficiency of 100 percent, it then follows, for the magnitude of the energy concentration, that we have: $C_{Det} \approx 2{,}6 \cdot 10^{25}\ \mathrm{MeV} : 2{,}6\ \mathrm{cm}^3 \approx 10^{25}\ \mathrm{MeV\,cm}^{-3}$ and in case of $\eta = 0{,}2\ C_{Det} \approx 2 \cdot 10^{24}\ \mathrm{MeV\,cm}^{-3}$.

In general we can thus show that the initial energy concentration in nuclear fission weapons as a function of the efficiency is on the order of magnitude of 10^7 kcal cm^{-3}.[36]

Table 1.11. Comparison of Energy Concentrations from Detonations of Nuclear Fission Weapons and the Explosive TNT

	Nuclear weapon	TNT
Energy concentration, kcal cm^{-3}	10^7	1.5
Maximum temperature in reaction zone °K	$30 \cdot 10^6$	$5 \cdot 10^3$
Maximum pressure in reaction zone, atm abs	$20 \cdot 10^9$	$2 \cdot 10^5$

The maximum temperature in the reaction zone can approximately be estimated as follows:

$$T = \sqrt[4]{\frac{E_{Det}}{\theta \cdot F_{KL} \cdot t_1}} \qquad (1.19)$$

T--Thermodynamic temperature/°K
E_{Det}--Detonation energy/erg; see Formula 1.9
θ--Constant ($\theta = 5.7 \cdot 10^{-5}$ erg $cm^{-2} s^{-1} °K^{-4}$)
F_{KL}--Surface of nuclear charge/cm^2 ($F_{KL} \approx 30 \cdot q^{2/3}$)
t_1--Time/sec during which 90 percent of the detonation energy are released; see Table 1.8 or Formula 1.18.

The maximum pressure in the reaction zone can be estimated roughly as follows:

$$p = 9{,}87 \cdot 10^{-7} \cdot m \cdot k \cdot T \qquad (1.20)$$

p--Maximum pressure in reaction zone/atm abs
m--Number of particles per cm^3 gas/^{1}[illegible]/cm^3
k--Boltzmann constant ($k = 1.38054 \cdot 10^{-16}$ erg $°K^{-1}$)
T--Thermodynamic temperature/°K

The formula given for the calculation of the maximum pressure in the reaction zone goes back to the kinetic gas theory according to which the gas pressure is roughly proportional to the number of particles per volume unit and the thermodynamic temperature.[37] For the computation we can assume roughly the following:

$$m \approx 4 \cdot 10^{24} cm^{-3}.$$

Review Questions

1.11. What fundamental connection is there between nuclear binding energy and mass effect?

1.12. What basic conclusions concerning the possibility of releasing nuclear energy result from the diagram illustrating the average nuclear binding energy per nucleon as a function of the mass number A?

1.13. How can one explain the stability or instability of a certain nuclide?

1.14. Under what conditions can nuclear explosives be split by thermal neutrons?

1.15. What do we mean by the concept of chain reaction?

1.16. What is the influence of the magnitude of the neutron multiplication factor k on the course of energy release?

1.17. Through what design measures can the magnitude of the critical mass in nuclear fission weapons be influenced?

1.18. Explain the basic structure of nuclear weapons.

1.19. What are the ways to convert the nuclear charge from the subcritical to the supercritical state?

1.20. What is the course of the internal detonation process in nuclear fission weapons?

1.21. What are the functions of the casing of a nuclear fission weapon?

1.22. Why are subcaliber nuclear weapons "uneconomical?"

1.23. What are the energy concentrations during the detonation of nuclear fission weapons?

1.24. Under what conditions are deviations from the standard intensity given possible in the detonation of nuclear fission weapons?

1.4. Structure of Multi-Phase Nuclear Weapons and Nuclear Synthesis Weapons

1.4.1. Nuclear Synthesis as Foundation of Energy Release

As we showed in Section 1.3.1.1., there is a second, basically different possibility—nuclear synthesis—in addition to the possibility of obtaining nuclear energy through the fission of heavy nuclei.

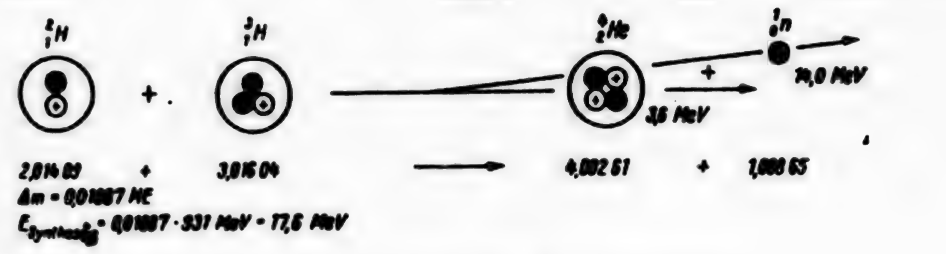


Figure 1.11. Basic diagram illustrating nuclear synthesis.

In a nucleus synthesis reaction, two atomic nuclei are combined. As a result of this nuclear fusion, there is an excited intermediate nucleus which as a rule again decays, emitting protons, neutrons, or alpha particles. Here again the released energy amount is determined by the difference in the nuclear binding energy of the original and terminal nuclei of each reaction.[38]

Table 1.12. Relative Atomic Mass of Some Important Nuclides[39]

1	2	1	2
Nuklid	relative Atommasse ME	Nuklid	relative Atommasse ME
$^{1}_{0}n$	1,00865	$^{3}_{2}He$	3,01602
$^{1}_{1}H$	1,00782	$^{4}_{2}He$	4,00261
$^{2}_{1}H$	2,01409	$^{6}_{3}Li$	6,01512
$^{3}_{1}H$	3,01604	$^{7}_{3}Li$	7,01600

Key: 1--Nuclides; 2--Relative atomic mass.

For example, for the most important nuclear synthesis reaction $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ we get an energy amount of 17.6 MeV.

During nuclear fission, less than 1,000 of the mass of the participating nuclei is converted into energy; in nuclear synthesis however--depending upon the reaction--as much as 7/1,000 are thus converted.

To overcome the electrostatic potential barriers of the nuclei participating in a nuclear synthesis reaction, they must be accelerated to a certain minimum energy. Because the size of the Coulomb forces grows along with the nuclear charge number, a blending of light nuclei can be accomplished with a considerably lesser energy expenditure than in the case of heavy nuclei. The magnitude of the potential barrier for deuterium (^{2}H) thus is about 0.01 MeV whereas for the lithium isotope $^{7}_{3}Li$ it is already $^{1}0.4$ MeV.

If we start with the equation:

$$E = \frac{m}{2} \cdot v^2$$

and if we dissolve it for v, then we get the following expression for the average velocity needed for the nuclide that triggers the nuclear synthesis reaction:

$$v = \sqrt{\frac{2E}{m}} \qquad (1.21)$$

v--Average velocity of nuclide/m sec^{-1}
E--Magnitude of potential barrier to be overcome in the particular reaction/kg m^2 sec^{-2}.

The following applies:

$$1\ \text{MeV} = 1{,}602 \cdot 10^{-13}\ \text{J} = 1{,}6 \cdot 10^{-13}\ \text{Nm} = 1{,}602 \cdot 10^{-13}\ \text{kg}\,\text{m}^2\,\text{s}^{-2}$$

m--Absolute atomic mass/kg

$$1\ \text{ME} = 1{,}66043 \cdot 10^{-27}\ \text{kg}$$

For the synthesis reaction:

$$^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}^{1}_{0}\text{n}$$

According to Formula 1.21 we thus get an average required velocity for deuterons as follows:

$$v = \sqrt{\frac{2 \cdot 0{,}01 \cdot 1{,}602 \cdot 10^{-13}\ \text{kg}\,\text{m}^2\,\text{s}^{-2}}{2{,}01409 \cdot 1{,}66043 \cdot 10^{-27}\ \text{kg}}} \approx 0{,}98 \cdot 10^{6}\ \text{m}\,\text{s}^{-1}$$

In a similar manner, for the necessary average velocity of a deuteron to overcome the potential barrier of $^{7}_{3}\text{Li}$, we get the value $v \approx 6.2 \cdot 10^{6}$ m s^{-1}.

The average molecular velocity v of hydrogen at a temperature of T = 300 °K is about $2 \cdot 10^{3}$ m s^{-1}.

Because, according to the kinetic gas theory, the squares of the average velocities of the particles behave like their thermodynamic temperatures (absolute temperatures), we can--using these numerical values--determine the temperatures corresponding to the above-calculated average particle velocities:

$$v_1^2 : v_2^2 = T_1 : T_2 \tag{1.22}$$

If we insert the corresponding values, we find that, corresponding to the velocities of the deuterons, amounting $v = 0.98 \cdot 10^{6}$ m s^{-1} or $v = 6.2 \cdot 10^{6}$ m s^{-1}, we get temperatures of $T = 7.2 \cdot 10^{7}$ °K or $T = 2.9 \cdot 10^{9}$ °K.

From this we arrive at the conclusion that, in contrast to nuclear fission reactions, nuclear synthesis reactions take place only at very high temperatures.

Table 1.13. Reference Values for the Velocities of Various Nuclides and the Absolute Temperatures Corresponding to these Velocities to Overcome the Potential Barriers of ^2_1H and ^7_3Li.

	1		1	
	^2_1H (Potentialwall: 0,01 MeV)		^7_3Li (Potentialwall: 0,4 MeV)	
	$v/m\,s^{-1}$	$T/°K$	$v/m\,s^{-1}$	$T/°K$
^1_1H	$1,4 \cdot 10^6$	$1,5 \cdot 10^8$	$9,8 \cdot 10^6$	$7,2 \cdot 10^9$
^2_1H	$9,8 \cdot 10^5$	$7,2 \cdot 10^7$	$6,2 \cdot 10^6$	$2,9 \cdot 10^9$
^3_1H	$8,0 \cdot 10^5$	$4,8 \cdot 10^7$	$5,1 \cdot 10^6$	$2,0 \cdot 10^9$

Key: 1--Potential barrier.

The basic problem complex in nuclear synthesis consists in the fact that the nuclei that can react must be approached to each other against their electrostatic repulsion forces to the distances of the effect of nuclear forces.

Nuclear synthesis reactions as thermonuclear reactions are based on the fact that the atomic nuclei to be fused must be imparted the kinetic energy necessary to overcome the Coulomb forces through temperature increases.

Thermonuclear reactions do not take place in the form of a chain reaction. Instead it is necessary to heat all nuclei to be made to react with each other first of all to a certain reaction temperature. These minimum temperatures depend on the particular nuclear synthesis charge and are on the order of magnitude of 10^6 to 10^8 °K. This kind of statement might be considered a contradiction to the values in Table 1.13. But in practice there are three reasons why the ignition temperatures of nuclear synthesis charges can be considerable among those in the table mentioned, to wit: The tunnel effect, the relative velocity of nuclei to be fused, and the statistical energy distribution of the nuclear particles in the plasma of the nuclear charge. Without going into any more detailed explanation of the tunnel effect[40] we might take a somewhat closer look at the two last-mentioned problems.

Assuming that the nuclear synthesis charge is converted to the plasma state due to energy supply from the outside, the energy of both nuclei participating in the reaction is critical for the materialization of a nuclear fusion. Because all nuclear particles present in the plasma have the same average temperature, the following condition can be derived in the most favorable case from Formula 1.21.

$$v = \sqrt{\frac{2E}{m_1 + m_2}} \qquad (1.23)$$

For the reaction ($^2_1H+^3_1H$) this gives us the values v = $6.2 \cdot 10^5$ m s^{-1}, T = $2.9 \cdot 10^6$ °K and for the reaction ($^1_1H+^7_3Li$) we have v = $3.1 \cdot 10^6$ m s^{-1}, T = $7.2 \cdot 10^8$ °K. Concerning the statistical energy distribution, one must keep in mind that, because of the number of countless completely irregular collisions of particles among each other, their particular momentary velocities can deviate heavily from the average value of the particle speed of the corresponding temperature [as published]. This means that individual nuclear particles can perform nuclear synthesis reactions also below the minimum temperature of the entire plasma.

The velocity, with which the individual nuclear synthesis reactions take place, depends primarily on the temperature of the charge mass. Here, the temperature is a measure for the average energy $\bar{E}$ of the nuclei to be fused. The minimum energy necessary for the materialization of a synthesis reaction is referred to as E_{min}. We get the following picture in a simplified manner: when $\bar{E} < E_{min}$ the probability of nuclear synthesis is extremely low but it is not zero. This is due to the fact that, because of the statistical energy distribution, individual nuclei have an energy which is above E_{min}. The mass of positive nuclei however will lose its kinetic energy which, on the average, is too small for nuclear reactions, due to impact or ionization processes. Here, their energy is reduced and the atomic nuclei are converted into neutral atoms due to electron capture.

In case of $\bar{E} > E_{min}$, the general prerequisites however do exist for the course of nuclear synthesis reactions. But here again the atomic nuclei lose a great part of their energy due to ionization so that the energy generated during synthesis reactions is not enough to balance out this energy loss and to keep the reaction going. From this springs the need for constant external energy supply. The reaction time for nuclear synthesis is relatively long.

When we have $\bar{E} >> E_{min}$, that is to say, in case of extremely high temperatures in the charge mass, we on the other hand get a very high effect cross-section from nuclear synthesis. During the rise in the temperature of a gas, the intensity of molecular heat movement grows quickly. At temperatures of several million degrees, the gas molecules are decomposed not only into the atoms constituting them but, in the case of the light elements hydrogen, helium, and lithium, the electron envelopes are split off from the atomic nuclei and we get a plasma consisting of freely moving atomic nuclei and electrons with a very high energy concentration. As a result, the ionization processes recede very much and the energy released due to nuclear synthesis is practically completely available for further temperature rises in the entire charge mass. It follows from this that the summary reaction time of a nuclear synthesis charge will be all the smaller, the higher its temperature is. At a certain temperature, the reaction time finally becomes so short that the reaction can take place in a lightning manner, in other words, as a detonation.

The possible utilization of certain thermonuclear reactions is determined especially by four characteristics:

The possibilities of producing the particular nuclear explosive, its cost, as well as its general physical and chemical properties;

The energy balance of the particular reaction, that is to say, the detonation energy that can be released per charge unit;

The reaction velocity of the thermonuclear reaction;

The ignitability of the nuclear synthesis charge at the temperatures generated by the weapon's fuse.[41]

Table 1.14 shows that the energy balance of the individual thermonuclear reactions differs widely. In this kind of estimate one must however not start only with the existing "pure nuclear explosives" but one must instead also look at the particular physical and chemical properties of the corresponding compounds in which the nuclear explosive is introduced into the weapon.

For example, for every kilogram of nuclear explosive during reaction (5), related to pure deuterium and tritium, we get a TNT equivalent of 84 kt. If however we were to start with the assumption that deuterium and tritium are present as heavy or superheavy water, then we would get a value of 18 kt.

The time from the ignition of a nuclear weapon to its decay is on the order of several microseconds. It follows from this that only thermonuclear reactions taking place within this order of magnitude can be used for nuclear weapons. Here naturally the generated temperatures and the densities of the charge mass also play a decisive role because the synthesis reactions in each case must take place so fast that the charge will not be decomposed prematurely. This is why, for example, we can from the very first eliminate reactions (1) and (4) because the reaction times would be too long even at temperatures on the order of magnitude of $200 \cdot 10^6$ °K.

The problems are similar regarding the ignitability of the nuclear synthesis charge. The greater the heat volume released by the fuse, that is to say, the higher the temperatures to which the nuclear synthesis charge is raised, the greater will be the possibility of also utilizing reactions with relatively long reaction times because they after all are a function of the charge temperatures (see the data in the table).

It is therefore important to insert as few ballast materials into the nuclear weapon as possible.

Table 1.14

1 Ausgangselemente			2 Kernsynthesereaktion		3 Reaktionsenergie	4 Energie je Kilogrammatom	5 Energie je kg Ladung *	6 Reaktionszeit/s bei **	
7 Reaktionsbedingungen	8 Kernteilchen		9 Ausgangskerne	10 Endkerne	MeV	kcal	kt	$20 \cdot 10^6$ °K	$200 \cdot 10^6$ °K
$p > 10^9$ at	Proton ${}^1_1H$	1	${}^1_1H$ → ← ${}^2_1H$	${}^3_2He$	5,5	$128 \cdot 10^6$	42	-	0,5
$T > 2 \cdot 10^7$ °K	Neutron ${}^1_0n$	2	${}^2_1H$ → ← ${}^2_1H$	${}^3_2He$ + ${}^1_0n$	3,3	$75 \cdot 10^6$	19	$1,9 \cdot 10^{-3}$	$1,9 \cdot 10^{-6}$
11 Reaktionszeit < 1...2 µs	Deuterium ${}^2_1H$	3	${}^2_1H$ → ← ${}^2_1H$	${}^3_1H$ + ${}^1_1H$	4,0	$93 \cdot 10^6$	23	$1,9 \cdot 10^{-3}$	$1,9 \cdot 10^{-6}$
	Tritium ${}^3_1H$	4	${}^1_1H$ → ← ${}^3_1H$	${}^4_2He$	19,8	$456 \cdot 10^6$	113	-	0,5
	Lithium ${}^6_3Li$	5	${}^2_1H$ → ← ${}^3_1H$	${}^4_2He$ + ${}^1_0n$	17,6	$405 \cdot 10^6$	81	$3,9 \cdot 10^{-8}$	$2,4 \cdot 10^{-7}$
		6	${}^3_1H$ → ← ${}^3_1H$	${}^4_2He$ + 2 ${}^1_0n$	11,3	$261 \cdot 10^6$	43	-	-
		7	${}^6_3Li$ → ← ${}^2_1H$	${}^7_3Li$ + ${}^1_1H$	5,0	$116 \cdot 10^6$	14	$7,5 \cdot 10^{-3}$	$7,5 \cdot 10^{-5}$
		8	${}^6_3Li$ → ← ${}^2_1H$	${}^4_2He$ + ${}^4_2He$	22,3	$515 \cdot 10^6$	64	$7,5 \cdot 10^{-3}$	$7,5 \cdot 10^{-5}$
		9	${}^7_3Li$ → ← ${}^1_1H$	${}^4_2He$ + ${}^4_2He$	17,3	$399 \cdot 10^6$	58	$1,8 \cdot 10^{-3}$	$4,5 \cdot 10^{-5}$
			12 Spaltung von U-235 als Vergleich		200	$4600 \cdot 10^6$	20	-	-

Key: 1--Initial elements; 2--Nuclear synthesis reaction; 3--Reaction energy; 4--Energy per kilogram atom; 5--Energy per kg of charge; 6--Reaction time/sec at; 7--Reaction conditions; 8--Nuclear particles; 9--Original nuclei; 10--Terminal nuclei; 11--Reaction time; 12--Fission of U-235 for comparison; * The data relate to pure nuclear synthesis products; in practice it would have to be kept in mind that the reacting nuclides can be bound to certain "ballast substances"; ** The literature on the subject presents widely differing values for the reaction time; this due to the fact that the concentrations of nuclear explosives (chemical structure, density), used as basis for the computations, plays a big role.

1.4.2. Basic Elements of Multi-Phase Nuclear Weapons

There are less specific data in the literature on multi-phase nuclear weapons than on the nuclear fission weapons. Besides, their structure is considerably more complicated. This is why the following presentations must be confined to several basic viewpoints.

In contrast to nuclear fission weapons, the detonation process, when we use nuclear synthesis, as a rule takes place in several phases. Here we distinguish detonation processes which take place in two or three successive phases.

The advantages of this type of weapon consist particularly in the fact that the raw materials generally are more available and that the size of the nuclear charge is not limited upward by any critical mass.

For the synthesis phase we use mostly the nuclides $^{1}_{1}H$, $^{2}_{1}H$ (Deuterium), $^{3}_{1}H$ (tritium), and $^{6}_{3}Li$, in an elementary form or in the form of chemical compounds ($^{2}_{1}H_2O$, $^{3}_{1}H_2O$, $^{6}_{3}Li^{2}_{1}H$, $U^{2}_{1}H_3$, $U^{3}_{1}H_3$, etc.).

The first phase of the detonation process in multi-phase nuclear weapons serves for the generation of the ignition temperatures necessary to initiate the nuclear synthesis reactions. For this we use one or more nuclear fission fuses. The temperatures generated are on the order of magnitude of several tens of millions of degrees (see Section 1.3.4.).

Under this assumption, the reaction of the nuclear synthesis charge can not only be maintained but can even be speeded up through the thermal energy released during synthesis, under certain conditions. But for that we must make sure that a sufficiently large mass of nuclear synthesis charge will be made to react as a result of the course of the ignition phase. Furthermore, the velocity of heat transfer to the outside must be slow; that is to say, the heat losses must be considerably less than the heat quantity generated during the same time interval through synthesis. If these conditions are not met, then the reaction will quickly be broken off and we get a poor efficiency for the utilization of the thermonuclear charge.

Relations 1.8 to 1.10 apply fully in terms of content regarding the total equivalent of a multi-phase nuclear weapon as given in Section 1.3.2.1. In computing the number of nuclear synthesis reactions necessary for the generation of a certain detonation intensity we must however keep in mind that a part of the total energy comes from nuclear fission. This is why we have the following relationship corresponding to Formula 1.11 for the number of nuclei necessary for synthesis z:

$$z = \frac{E'_{Det} - E_{Det}}{0,5\,\Delta E_{Syn}} \text{ nuclei} \qquad (1.24)$$

E'_{Det}--Total detonation energy from fission and synthesis

E_{Det}--Nuclear fission energy from fuse

ΔE_{syn}--Energy released during fusion of two nuclei.

We thus get the following in a similar manner for the mass of the nuclear synthesis charge related to pure synthesis substances:

$$Q' = 0.5\,z\,\frac{1}{N_{A_1}} + \frac{1}{N_{A_2}}\ \text{kg} \qquad (1.25)$$

whereby the Avogadro constant (see Section 1.3.2.1.) in each case is related to the kilogram atoms of the nuclides participating in synthesis.

If we use Formula 1.25 however we must observe two restrictions. First of all, nuclear synthesis, with relation to the total charge, only has a certain efficiency and, besides, we must keep in mind the chemical compound in which the initial materials are present because the ballast substances must also be included in the computation of the entire charge mass. If, for example, deuterium is present in the bonded state in heavy water, then oxygen will act as ballast.

Because the structure and process of energy release in the various types of multi-phase nuclear weapons can vary greatly, we will in the following briefly describe some possible variants.

1.4.2.1. The Deuterium-Tritium Two-Phase Nuclear Weapon

The deuterium-tritium nuclear weapon represents the prototype of thermonuclear weapons. It came at the beginning of American development in this field while the Soviet Union obviously skipped that step.

The main components of this weapon are the nuclear fission fuse or fuses, the nuclear synthesis charge, the detonation device, and the casing. Following our earlier explanations, it is at this point only necessary to cover the energy release during the second detonation phase.

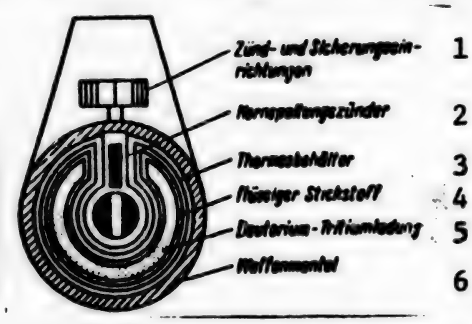


Figure 1.12. Basic structure of two-phase nuclear weapon with deuterium-tritium nuclear charge. Key: 1--Ignition and safety devices; 2--Nuclear fission fuse; 3--Thermos container; 4--Liquid nitrogen; 5--Deuterium-tritium charges; 6--Weapon casing.

A mixture of deuterium and tritium is used as nuclear explosive in this type. Both deuterium and tritium are gaseous under standard conditions. This gives us an extremely complicated construction because the required high charge density of the deuterium-tritium mixture must be achieved through liquefaction. This calls for very low temperatures (-250°C). To keep the deuterium-tritium mixture in a liquid state, it must be placed in a special thermos system. We furthermore need cooling units and evacuation systems. All of these installations however are very difficult to place in a transportable weapon because of their circumference and weight.

"The air is pumped out of the space between the walls of the thermos container and the heat influx is thus reduced. Such a vessel is placed in a vessel with the same structure into which we pour liquid nitrogen at a temperature of about -190 °C. Into the inner vessel we put liquid hydrogen, deuterium, or tritium which must be kept at a temperature of about -250 °C. But hydrogen will evaporate comparatively quickly even from those vessels."[42]

The energy release during the nuclear synthesis phase takes place according to the reaction (5), Table 1.14 (cf. ibid.):

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6\ MeV$$

The required ignition temperature of about 10^7 °C is generated by the nuclear fission fuses. The further course of the thermonuclear reaction is guaranteed by the energy surplus released during synthesis. From the reaction illustrated we can see that about 20 percent of the reacting synthesis charge are converted into free neutrons. The energy of these neutrons is 14 MeV.

1.4.2.2. The Lithiumdeuteride Two-Phase Nuclear Weapon

This nuclear weapon type is a design which in the literature is often referred to as "dry bomb." Here the gaseous hydrogen isotopes deuterium and tritium are completely or for the most part replaced with the solid nuclear explosive lithiumdeuteride. This yields a large number of advantages, compared to the above-described weapon, both in terms of production and in terms of weapon engineering.

Lithiumdeuteride $^{6}_{3}Li^{2}_{1}H$, which is used as nuclear explosive, like the other lithium hydrogens, is a solid, stable, and easily stored compound which can be produced on a large industrial scale relatively cheaply.

Since it is possible to make the nuclear reactions take place in such a manner that the tritium, necessary for deuterium-tritium synthesis, need not be inserted into the weapon, but is generated immediately as a result of nuclear reactions, the production costs of this nuclear weapon type decline enormously.[43] Tritium is not only difficult to make but its storability is also limited because it is radioactive and decays with a half-life of only 12.5 years.

The principle of energy release of a nuclear weapon with lithiumdeuteride charge can be illustrated schematically roughly as follows: During the first

detonation phase we have the ignition of the nuclear fission arrangement to generate the necessary reaction temperature in the nuclear synthesis charge. At the same time, a strong neutron flow develops during nuclear fission.

As a result of this, we have the following nuclear reactions:

$$\text{(a)}\quad {}^{6}_{3}\mathrm{Li} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{3}_{1}\mathrm{H} \qquad + 4{,}8\ \mathrm{MeV}$$
$$\text{(b)}\quad {}^{2}_{1}\mathrm{H} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{3}_{1}\mathrm{H} \qquad + 6{,}2\ \mathrm{MeV}$$

The tritium, developing in this fashion, reacts with the deuterium--the nuclear synthesis reactions take place as a function of the temperature of the charge mass and thus the reaction times parallel to each other--according to the well-known equation:

$$\text{(c)}\quad {}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} \qquad + 17{,}6\ \mathrm{MeV}$$

At the same time, the following nuclear reactions take place:

$$\text{(d)}\quad {}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \begin{cases} \nearrow\ {}^{3}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} & + 4{,}0\ \mathrm{MeV} \\ \searrow\ {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} & + 3{,}3\ \mathrm{MeV} \end{cases}$$

Due to the temperature rise in the charge mass to 10^8 °K and more, caused by these reactions, the following reactions then also gain significance proportionally:

$$\text{(e)}\quad {}^{6}_{3}\mathrm{Li} + {}^{2}_{1}\mathrm{H} \rightarrow 2\,{}^{4}_{2}\mathrm{He} \qquad + 22{,}3\ \mathrm{MeV}$$
$$\text{(f)}\quad {}^{3}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} \qquad + 19{,}8\ \mathrm{MeV}$$
$$\text{(g)}\quad {}^{6}_{3}\mathrm{Li} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{He} \qquad + 5{,}0\ \mathrm{MeV}$$

A closer look at the nuclear synthesis reactions mentioned here in the light of Table 1.14 makes it clear that the lithium synthesis reactions require a considerably higher initial temperature for the rapid course of the overall process than is the case with the pure deuterium-tritium mixture. Here we might visualize the following solutions, among others: First of all it is possible to use a certain quantity of deuterium and tritium as so-called transition detonator; besides, solid lithiumtritide compounds are suitable for the same purpose.

By way of summary we can say that the use of solid nuclear explosives to begin with created the possibilities for the manufacture of usable multi-phase nuclear weapons because it was possible in this way considerably to reduce the dimensions and weights of the corresponding constructions.

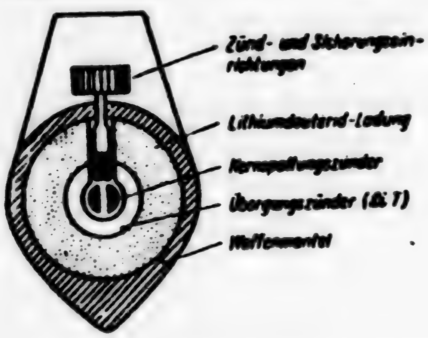


Figure 1.13. Basic structure of two-phase nuclear weapon with lithium-deuteride nuclear charge. Key: 1--Ignition and safety devices; 2--Lithium-deuteride charge; 3--Nuclear fission fuse; 4--Transition fuse (Li 7); 5--Weapon casing.

1.4.2.3. The Three-Phase Uranium Jacket Nuclear Weapon

In this nuclear weapon type, the detonation energy is generated in succession through nuclear fission--nuclear synthesis--nuclear fission. The first and second phases of this energy release basically take place as in two-phase nuclear weapons. The new thing in the three-phase nuclear weapon consists in the fact that most of the total energy of the detonation comes from the third phase, the fission of the U-238 jacket.

In our coverage of the fundamentals of nuclear fission in Section 1.3.1.2., we already pointed out that fast neutrons are necessary to split the nuclei of the uranium isotope U-238. This is also made clear by the data in Table 1.5 concerning the activation energy of U-238. Although fission neutrons with an energy of 2 MeV are released as a result of the nuclear fission of U-238, this is not enough for further nuclear fission in the manner of a chain reaction because these neutrons quickly lose energy due to elastic and inelastic collision processes so that their kinetic energy very quickly winds up below the required value of the activation energy.

The fission of a nuclear charge consisting of U-238 thus presupposes that the energy-rich neutrons, necessary for this, are supplied from the outside. The nuclear synthesis phase represents such an "external neutron source."

The detailed illustration of the nuclear synthesis reactions in Table 1.14 shows that neutrons are released during reactions (2), (5), and (6). The energy of these neutrons is 2.5 MeV in reaction (2) and 14 MeV in reaction (5).

These superfast neutrons--during deuterium-tritium synthesis, their share, as we said before, is 20 percent, by the way--are used for the fission of U-238.

Here, regarding the arrangement of the nuclear charge, the isotope mixture provided for synthesis and the U-238 which is to be split can form a uniform whole in order to keep the energy release efficiency as high as possible.

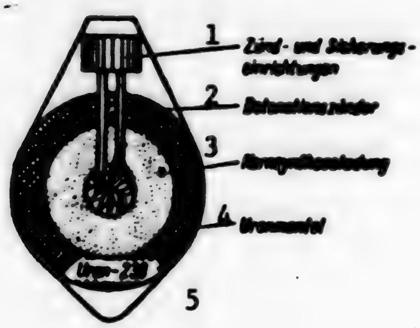


Figure 1.14. Basic diagram illustrating a three-phase uranium jacket nuclear weapon. Key: 1--Ignition and safety mechanisms; 2--Detonation fuse; 3--Nuclear synthesis charge; 4--Uranium jacket; 5--Uranium-238

Economic reasons are primarily responsible for the construction of the three-phase uranium-jacket nuclear weapon. U-238 accounts for more than 99 percent of the isotope mixture occurring in nature. It therefore can be produced cheaply and is obtained in many places as nuclear industry "waste product." Besides, long-drawn-out and expensive separation processes can be skipped here.

The following numerical example will serve to illustrate the energy release during the detonation of a three-phase nuclear weapon. But here we are dealing only with rough reference values. Each of the three energy release phases must reveal a balanced energy record and takes place by itself with a specific efficiency.

According to various data in the literature, we get the following conditions for a total equivalent 10 Mt:

To generate the necessary ignition temperature for the nuclear synthesis charge, plutonium fuses with an equivalent of 0.4 Mt are detonated during the first phase. Assuming an efficiency of 20 percent, the Pu-239 charge would have to be about 100 kg here.

For the second phase we need a synthesis charge with a deuterium-tritium equivalent of about 40 kg which supplies the required quantity of superfast neutrons. The energy share of this phase is 1.6 Mt. We assumed an efficiency of something like 50 percent. The flow of superfast neutrons from the synthesis phase is enough in order completely to split 400 kg U-238 and thus to release an energy amount of 8 Mt during the third phase. If we assume the efficiency of U-238 fission to be 10-15 percent, then a total of 4-5 t U-238 would have to be inserted into the weapon.

From what we have said so far we can deduce that Uranium-jacket nuclear weapons are suitable above all for getting detonation intensities in the Megaton range.

This assumption is confirmed among other things by a series of nuclear weapons tests during which the quantity of radioactive detonation products produced was proportional to the detonation intensities.

1.4.2.4. Multi-Phase Nuclear Weapons with Cobalt Jacket

In contrast to the function of the uranium jacket, which is used to release nuclear fission energy, the job of a cobalt jacket is not to increase the detonation energy but rather to produce additional large quantities of radioactivity. Although such constructions are very questionable from the military viewpoint, we might nevertheless present some viewpoints concerning such a weapon. Nuclear reactions as a result of which there is a powerful neutron flow can be used to trigger additional nuclear processes. Thus, it is possible, for example, if a nuclear weapon has an additional jacket of Co-59, to convert the latter into Co-60 through neutron capture. Co-60 is a beta-gamma-active radionuclide with a half-life of 5.3 years.

In a multi-phase nuclear weapon with a nuclear synthesis energy share of 10 Mt, about 1.5 t Co-60 can be produced in this fashion. This corresponds to an original radioactivity of $1.5 \cdot 10^9$ Curie or, by way of comparison, to the radioactivity of 1.5 million kg radium.

A high-altitude air burst of such a weapon would therefore lead to an extremely dangerous worldwide radioactive contamination of the atmosphere and the earth's surface which, because of the slow attenuation of radiation, would be connected with an enormous radiation exposure for large population segments. (See also the statements in Chapter 7, in this connection.)

1.4.3. Structure of Nuclear Synthesis Weapons

It follows from what we have said so far in Section 1.4.1. that minimum temperatures on the order of 10^6 °K are necessary to initiate thermonuclear reactions.

So long as one had to depend exclusively on nuclear fission fuses to generate these ignition temperatures in the synthesis charge, one could not speak of nuclear synthesis weapons, regardless of the ratio between the released detonation energies of the first and the second detonation phases.

A nuclear synthesis weapon within the meaning of the concept definition given in Section 1.1. thus exists only if it is possible to generate the necessary ignition temperatures in ways other than through nuclear fission fuses.

Some test detonations in years past and subsequent discussions in the literature indicate that such possibilities obviously exist not only in terms of theory but that they are already being used in practice to a certain degree. In looking at this kind of statement there is no question that the production of a "clean" nuclear synthesis weapon introduces a whole series of extremely complicated problems in physical-technical respects.

Kotchari[44] already pointed out that there is basically a possibility of using ordinary chemical explosives to initiate thermonuclear reactions. Reference was made here to the generation of the required ignition temperatures by means of successive hollow-charge explosions.[45]

According to available data, it is possible in this fashion to obtain gas velocities of up to 100 km s^{-1}; this would correspond to a temperature on the order of 10^6 °K.

We may, for example, estimate that the ignition of an adequate quantity of a deuterium-tritium mixture would require an external energy supply amounting to several billion Joule. But it so happens that the probability of ignition of a nuclear synthesis charge is determined not just by the amount of energy supplied. It grows, the shorter the time spent for that happens to be. If we assume an environmental pressure of about $2 \cdot 10^5$ atm abs, then we get a figure 10^{-8} sec for the time duration of ignition.

Considering the fact that known chemical explosives do not permit such extremely short ignition times, it would be conceivable to bind the energy, released by the explosive charge, for several milliseconds by means of electromagnetic fields; that is to say, to convert them into magnetic energy through field condensation and thus to get the necessary energy concentration with the corresponding short action time over several stages.

Wherein do the "advantages" of nuclear synthesis weapons reside?

The synthesis products resulting from the detonation are not radioactive. This means that, even in case of surface of underground detonations of these weapons, we need not figure on getting large areas of radioactively contaminated land. Terrain contamination is practically reduced to the neutron-induced radioactivity of the area immediately around the detonation.

It would furthermore seem to be possible in this way to produce nuclear weapons on the order of several hundred kilotons in an economical fashion. But there are as yet no further official details available on that.

In connection with nuclear synthesis weapons, we would like, in conclusion, to take up two concepts used in the literature on the subject from time to time: The so-called "clean nuclear weapon" and the "neutron bomb."

As we briefly explained regarding this problem complex in Section 1.2., both concepts came up in Western literature in conjunction with the propagation of an alleged superiority on the part of the United States in nuclear weapons development. This connection already clearly shows that most of these publications were not based on specifically natural-science facts but that their main concern was and is aimed at political and military speculations.

The question as to the "clean nuclear weapons" is relatively simple.

Basically we are dealing here with nuclear synthesis weapons, in other words, devices whose energy release is based exclusively on nuclear synthesis, or such two-phase nuclear weapons where the energy share from the nuclear fission phase is negligibly small and where, due to suitable design details--for example, a weapon jacket which will be practically indifferent regarding neutron capture--we get no further radioactive detonation products other than the neutron-induced radioactivity in the detonation area.

Here, the characteristic magnitudes of the destructive effects of the blast wave and light radiation are naturally not changed.

Concerning the "neutron bomb," this is a concept which the imperialist press did not try to define anywhere, not even making an attempt to do so. From the physical viewpoint, the main feature of such a weapon would have to consist of the fact that the entire releasable energy or at least most of it would appear as a neutron flow. This is why the question as to the neutron bomb boils down to what possibilities there are for generating the required neutron flow densities according to military viewpoints without releasing any large quantities of heat because in this case the development of a blast wave and light radiation are unavoidable.[46]

This is why methods for the generation of high neutron flow densities, through detonation-like processes, can be ruled out from the very beginning and that also eliminates processes of nuclear fission and nuclear synthesis--unless, of course, one were to consider a controlled chain reaction (reactor). Such a device however is more than doubtful for a whole series of reasons, just like the use of special electrical accelerators or neutron sources.[47]

Without going into any further details, we might observe here that a "clean" neutron weapon, not based on the detonation principle, would have only a relatively small action radius. This means that the thing that is more debatable is the version of a neutron weapon in which the neutron flow is particularly emphasized as compared to the other destruction factors. This is entirely the case, for example, with nuclear synthesis weapons, as we said earlier.

In looking into this question one must furthermore also keep in mind that the ratio between the neutron flow as a destruction factor and the blast wave and light radiation as destruction factors is shifted in favor of the former especially at extremely low detonation intensities and that, assuming the detonation altitude is properly selected, one can create conditions under which the neutron flow becomes the main destruction factor against human beings.

According to various data, for example, a nuclear synthesis charge with an equivalent of 0.05 kt and a detonation altitude of 400 m is supposed to generate an overpressure in the blast wave front on the ground amounting to a maximum of 0.03 kp cm^{-2} and a light impulse of only 0.5 cal cm^{-2} whereas on a surface of about 0.5 km^2 around ground zero we can figure on a neutron dose of 400 rem plus 80 rem of gamma radiation.[48]

By way of summary it follows that this explains both the questions of "clean nuclear weapons" and of the "neutron bomb" with the help of the basic explanations given in sections 1.4.1. and 1.4.2 for the structure and energy release of nuclear weapons.

Review Questions

1.25. What is the essence of nuclear synthesis reactions during energy release from nuclear weapons?

1.26. What conclusions can be derived from the fact that thermonuclear reactions do not take place in the form of a chain reaction?

1.27. Using Table 1.14, explain the basic prerequisites for the possible utilization of certain thermonuclear reactions in multi-phase nuclear weapons or nuclear synthesis weapons.

1.28. Explain the basic structure of two-phase and three-phase nuclear weapons.

1.5. Footnotes for the Introduction and for Chapter 1

1. Team of authors, director: Sokolovskiy, V. D., "Militaerstrategie" [Military Strategy], German Military Publishing House, Berlin, 1965, p 246.

2. "The Working Committee of the Conventional Weapons Commission, established by the UN Security Council of 4 February 1947, has drawn up the following categories for mass annihilation weapons: The atomic explosive weapons, radioactive weapons, the murderous chemical and biological weapons, as well as any other weapon which will be produced in the future and whose effects resemble those of atomic bombs and the other weapons mentioned." Quoted from E. von Frankenberg, "Massenvernichtungswaffen" [Mass Annihilation Weapons], Publishing House of the MfNV [National Defense Ministry], Berlin, 1958, p 14.

3. Some additional changes in terminology, resulting from the historical development of nuclear weapons or springing from technical and scientific aspects, will be covered in detail in Section 1.2.

4. The literature from time to time contains such formal comparisons to the effect that a nuclear weapon with a detonation intensity of 20 kt TNT would correspond to the "explosive force" of 20,000 one-ton HE bombs. This of course is approximately correct concerning energy release but does not really tell us anything significant regarding the quality and quantity of the destructive effects.

5. Grichin, N., "On Some Development Directions in Warheads for Strategic Missiles of the United States," VOYENNIY ZARUBEZHNIK, 1970, 8, pp 29-36.

6. The picture was taken from Stephane Groueff, "Projekt ohne Gnade," Bertelsmann Sachbuchverlag Reinhard Mohn, Guetersloh, 1968, p 293 or pp 294-295.

7. The table was compiled according to data taken from an "Official Report of the United States Strategic Bombing Survey, The Effects of Atomic Bombs on Hiroshima and Nagasaki," New York, 1956, in an unauthenticated translation.

8. The International Red Cross Committee for example in No 383 of REVUE INTERNATIONALE DE LA CROIX ROUGE [International Magazine of the Red Cross],

Geneva, 1951, reports for the case of Hiroshima that "among the 200 doctors in the city of Hiroshima only 30 were in a position to do their job after the bomb had been dropped; out of the 45 hospitals in the city, only three were still usable." The numbers given in the table do not contain casualties due to delayed damage.

9. Quoted from the "Official Report of the United States Strategic Bomber Command," loc. cit., pp 2-4.

10. The picture was taken from "Medical Effects of the Atomic Bomb in Japan."

11. Truman, H., Memoirs, Vol II, "Years of Trial and Hope--1946-1953," pp 6, 7; German version, 1956, Alfred Schaerf Publishing House, Bern.

12. Irving, D., "The Virus Wing," Russian, Voyenizdat Publishing House, Moscow, 1969, translation from English.

13. Blackett, P. M. S., "Militaerische und Politische Folgen der Atomenergie" [Military and Political Questions of Atomic Energy], Berlin, 1949, p 173.

14. Von Frankenberg, "Massenvernichtungswaffen," loc. cit., p 17; Frankenberg uses official comments by the then United States Secretary of War Stimson (1940-1945).

15. See also Langhans, K., "Schriftenreihe Luftschutz" [Air Raid Protection Publication Series], Interior Ministry Publishing House, Berlin, 1960, No 2, p 5 f.

16. Based on a story in the newspaper NEUES DEUTSCHLAND [New Germany], 5 November 1961, p 1 (Republic edition).

17. The following general observation can be found regarding this point in the book entitled "Nuclear Detonation," New Delhi, 1956, Russian edition 1958, p 16: "It must however be remarked that--although the energy which was released during each of these detonations and which roughly corresponded to the detonation energy of 20,000 t of trotyl--the destruction surface corresponded to only 1/10 of the surface which would be exposed to destruction if this same quantity of trotyl were to be dropped on the target in the form of conventional bombs 'weighing' 1 t, each."

18. Aleksandrov, A. P., "The Power of the Atom," PRAVDA, 24 December 1966.

19. See also von Frankenberg, "Massenvernichtungswaffen," loc. cit., pp 354-364.

20. "The confirmation of the decision put an end to the long and bitter discussions that took place in the Atomic Energy Commission (chairman: David Lilienthal) and in its consultative committee (chairman: Robert Oppenheimer) and in the course of which completely different opinions were advocated concerning the possibilities and deadlines for the

production of the hydrogen bomb." Quoted from "Nuclear Detonations," loc. cit., p 14.

21. Data on the intensity of this detonation vary widely in the literature on the subject, among other things, from 2.5 to 10 Mt.

22. "Nuclear Detonations," loc. cit., p 19.

23. "The thermonuclear device was dropped from a B-52 jet bomber. The detonation presumably took place at an altitude of 5 km. The trotyl equivalent was estimated at Mt." THE TIMES, London, 21 May 1956.

24. Quoted from TAGESSPIEGEL [Daily Mirror], West Berlin, 5 November 1960.

25. Detailed descriptions of these events can be found in DER SPIEGEL [The Mirror], Hamburg 21, 1967, Nos 46-49 and 22, 1968, Nos 5 and 6.

26. The data in the table were compiled on the basis of a large number of literature sources. We might mention the most important of them here: "The Effects of Nuclear Weapons," prepared by the United States Department of Defense, Washington, 1962; "Die militaerische Staerke der Sowjetunion," [The Military Strength of the Soviet Union], published by the SED Central Committee, propaganda and agitation department, Berlin, November 1957; Nitz, J., "Mit uns der Sieg" [Victory Is on Our Side], Berlin, 1962; Jung, R., "Heller als tausend Sonnen" [Brighter than a Thousand Suns], Bern, Stuttgart, Vienna, 1956; Buehl, A., "Atomwaffen" [Atomic Weapons], Osang Publishing House, Ban Honnef, 1968; MILITAERWESEN, Vol 196-1970; Neue Zeit, Moscow, Vols 1961-1970; "Archiv der Gegenwart" [Archives of the Present], Bonn, Vienna, Zuerich, Vols 1965-1968; "Zivilschutz" [Civil Defense], Koblenz, 1962, 5, p 162; WEHRKUNDE [Defense Science], Munich, 1962, 12, p 681; 1965, 1, p 53; 1966; 5, p 272; 1971, 3, p 163; WEHRPOLITISCHE INFORMATIONEN [Defense Policy Information], Bonn, 1970, 11, p 6; NEUES DEUTSCHLAND, Berlin, 17 October 1964, 2 November 1964, 8 December 1964; Communications from the German Institute of Contemporary History, 1965-1970.

27. "Protocol of the International Conference of Communist and Worker Parties," Moscow, 1969, Dietz Publishers, Berlin, 1969, p 15.

28. For fast information on certain fundamentals of nuclear physics, the following are recommended in particular: "Kleine Enzyklopaedie Atom Struktur der Materie" [Small Encyclopedia, Atom, Structure of Matter], VEB Bibliographic Institute, Leipzig, 1970; Lindner, H., "Grundriss der Atom- und Kernphysik" [Outline of Atomic and Nuclear Physics], Specialized Book Publishing House, Leipzig, 1969.

29. The picture was used without any change: "Kleine Enzyklopaedie Atom," loc. cit., p 138.

30. The table was taken from "Kleine Enzyklopaedie Atom," loc. cit., p 184.

31. By 1 kilogram atom A kg we mean the relative atomic mass expressed in kilograms. For U-235, the value of the kilogram atom is roughly equal to 235 kg. The Avogadro constant tells us how many atoms or molecules are present in a kilogram atom or kilomol of any chemically uniform substance. Thus we find that 235 kg of U-235 contain $6.02252 \cdot 10^{26}$ atoms.

32. Further information on this problem complex concerning nuclear reactors can be found in Dubovskiy, B. G., and others, "Critical Parameters of Systems of Fissile Substances and Nuclear Plant Safety," Atomizdat Publishing House, Moscow, 1966, Russian.

33. "Nuclear Detonations," loc. cit., p 43.

34. Detailed descriptions on subcaliber nuclear weapons can be found among others in Langhans, K., "On the Question of Subcaliber Nuclear Weapons," MILITAERWESEN, 4, 1960, 2, pp 347-354.

35. According to a story in No 12, 1969, of the magazine URANIA, on page 39, the price of 1 g of Californium is presently reported to be $1 billion; it is supposed to take several years before 1 g of this chemical element can be produced annually.

36. In looking at the energy concentration, the detonation intensity plays a role only inasmuch as it must be assumed that various detonation intensities also reveal different efficiencies.

37. One cm^3 of nuclear charge contains about $5 \cdot 10^{22}$ atoms. When $\eta = 0.2$, 10^{22} nuclei are split off from that.

Each fission accounts for about 400 particles (nuclear fragments, neutrons and, mostly due to ionization, electrons). Both Formula 1.19 and Formula 1.20 are relatively independent of the detonation intensity. This is why the figures given in Table 1.11 for the maximum temperature and the maximum pressure in the reaction zone can serve generally to describe nuclear fission weapons. In the reaction zone we have the nuclear charge in the form of a plasma; this is why the electrons can be treated according to the kinetic gas theory. We must however not overlook the fact that widely differing values are being given in literature regarding the degree of ionization. This creates uncertainty when it comes to making a clear determination of m and thus also p.

38. The concept of nuclear synthesis reaction is used below both for processes of pure nuclear fusion and processes of nuclear decomposition reactions in which the nuclear mass of the developing nuclide is between those [masses] of the initial nuclides. Thermonuclear reaction and nuclear synthesis reaction are used as synonymous terms.

39. The values in this table were taken from Lindner, H., "Grundriss der Atom- und Kernphysik," loc. cit., p 99.

40. See ibid., p 136.

41. On these questions, see Neyman-Sadilenko, "Mehrphasenkernwaffen" [Multi-Phase Nuclear Weapons], German Military Publishing House, Berlin, 1961, pp 86 ff.

42. Ibid., p 76.

43. According to various literature data, 1 kg of tritium cost about $500 million in the United States at the beginning of development work.

44. See also "Nuclear Detonations," loc. cit., p 21.

45. Some comments on this problem complex can be found in A. Peyron, "Method and Device for the Ignition of a Nuclear Weapon," Patent No 1,350,078, dated 16 December 1963, Ministry of Industry of the French Republic; Hajek, "The Possibility of Nuclear Reactions by Means of Hollow Charges," WEHRTECHNISCHE MONATSHEFTE [Military Engineering Monthly], 57, 1960, 1, pp 8-21.

46. Generally understandable and summarizing statements on this problem complex can be found among others also in Calder, J., "What Do We Know about the Neutron Bomb?" INTERNATIONALE ZIVILVERTEIDIGUNG [International Civil Defense], Geneva, July-August 1961, Nos 73-74, p 1.

47. In making such statements, one must naturally keep in mind that one cannot rule out the fact that new physical methods of neutron production via the "cold way" may exist although they are not yet generally known. But this is less probable in this particular case.

48. A general comment on this problem complex can be found among others also in KRASNAYA ZVEZDA of 12 June, p 4, and 13 June, p 3, 1961. Colonel Glamov here covers the development of the neutron bomb and the Californium bomb. The latter is supposed to be a derivation of the neutron bomb. Reference is made here to additional possible interpretations of the concept "neutron bomb."

2. Outward Phenomena of Nuclear Weapon Detonation

2.1. Most Important Features of a Nuclear Weapon Detonation

The processes and phenomena connected with a nuclear weapon detonation are very multilayered and extraordinarily complicated. Only a part thereof is visible or can be perceived with the human sensory organs.

The impression which an observer gets regarding a specific detonation will among other things always depend on his position and his distance from the place of detonation and what observation means and possibilities he had available.

Regardless of that, the features of a nuclear weapon detonation are determined or influenced primarily by the detonation intensity, the detonation type, the weather and terrain conditions, and some other factors.[1]

In Hiroshima, the detonation of the 20-kt nuclear bomb took place at an altitude of 600 m. At the moment of the detonation, the detonation area was lit up glaringly by a jet of flame that was visible far away. After 0.1 msec, a fireball with a diameter of about 30 m developed. Its temperature was 300,000 °K and thus exceeded that on the surface of the sun about 50 times.

The fireball grew and rose rapidly. After 1 sec, it had reached a diameter of 300 m. The average velocity of upward movement was 100 $msec^{-1}$. After about 10 sec, the fireball was completely extinguished. Most of the light radiation was radiated over a period of 3 sec.

As a result of the extinction of the fireball, the detonation products were condensed and formed a characteristic, mushroom-shaped detonation cloud whose stem consisted of dust, ash, and masses of earth that had been swept up due to the suction resulting from the upward movement of the fireball or the detonation cloud. After 4-5 min, the detonation cloud had a diameter of 3 km and after 7 min reached an altitude between 10 and 15 km. The cloud remained stationary over the detonation area in this shape for some time and then began to break up due to the influence of high-altitude wind.

A dense, nontransparent dust and smoke cloud rose shortly after the detonation directly in the detonation area.

The detonation was accompanied by an extremely loud, shrill, and unpleasant noise.

A detonation in the Megaton range will develop in a manner similar to the features described here.

In November 1952, the United States exploded a nuclear weapon with an equivalent of 5 Mt in the region of the Marshall Island in the Pacific Ocean. The explosion took place right above the surface. One small island was completely obliterated. The diameter of the resultant crater was 1.5 km; its maximum depth was 50 m. Its volume was estimated at 0.05 km^3. The weight of the dirt and slag masses expelled by the detonation was about 50 million Mp.

The fireball's maximum diameter was 4 km. The detonation products rose to an altitude of 40 km and the detonation cloud, which developed roughly at an altitude of 15 km, reached a horizontal extent of 160 km.

In 1946, the United States conducted a 20-kt underwater detonation in the region of Bikini Atoll.

The detonation depth was 15 m. The water masses expelled by the detonation formed a water column which after 1 minute reached its maximum dimensions with a height of 2.5 km and diameters of 500 m at the base as well as 2,500 m at the cap. This corresponds to a water mass weighing 1 million Mp.

The most important external features of a nuclear weapon detonation include the fireball, the detonation cloud, and the detonation crater. Whether the detonations take place over land or over water plays a big role in the development of these features. It is furthermore necessary especially to consider the influence of the detonation intensity and the detonation altitude or depth. Conversely, it is naturally also possible with the help of these characteristics to make certain statements concerning the determination of the initial data of enemy nuclear weapon strikes.

2.1.1. The Fireball

On the basis of the extraordinarily high energy concentration and the fact that about 80 percent of the detonation energy originally appeared in the form of heat, the nuclear weapon is almost instantaneously vaporized during the detonation, whereby the gaseous detonation products initially hardly exceed the prior weapon volume and a fireball is formed.[2] In surface and underground detonations (underwater detonations), the fireball contains large quantities of vaporized and melted soil material (water) in addition.

The fireball from a nuclear weapon detonation represents a glaring bright, more or less spherical structure consisting of a cloud of glowing gases (plasma).

Because of the high energy concentration during the initial phase of its development, the fireball is the cause for the origin of a blast wave as well as, during its existence, the source of very intensive light and heat and radiation as well as an electromagnetic impulse.

The observation of the fireball's development is of interest in describing the destruction factor represented by light radiation, in explaining the origin and spread of the blast wave, and in characterizing the various detonation types.

The fireball's development can be broken down schematically into two periods of two stages, each (see Figure 2.1).

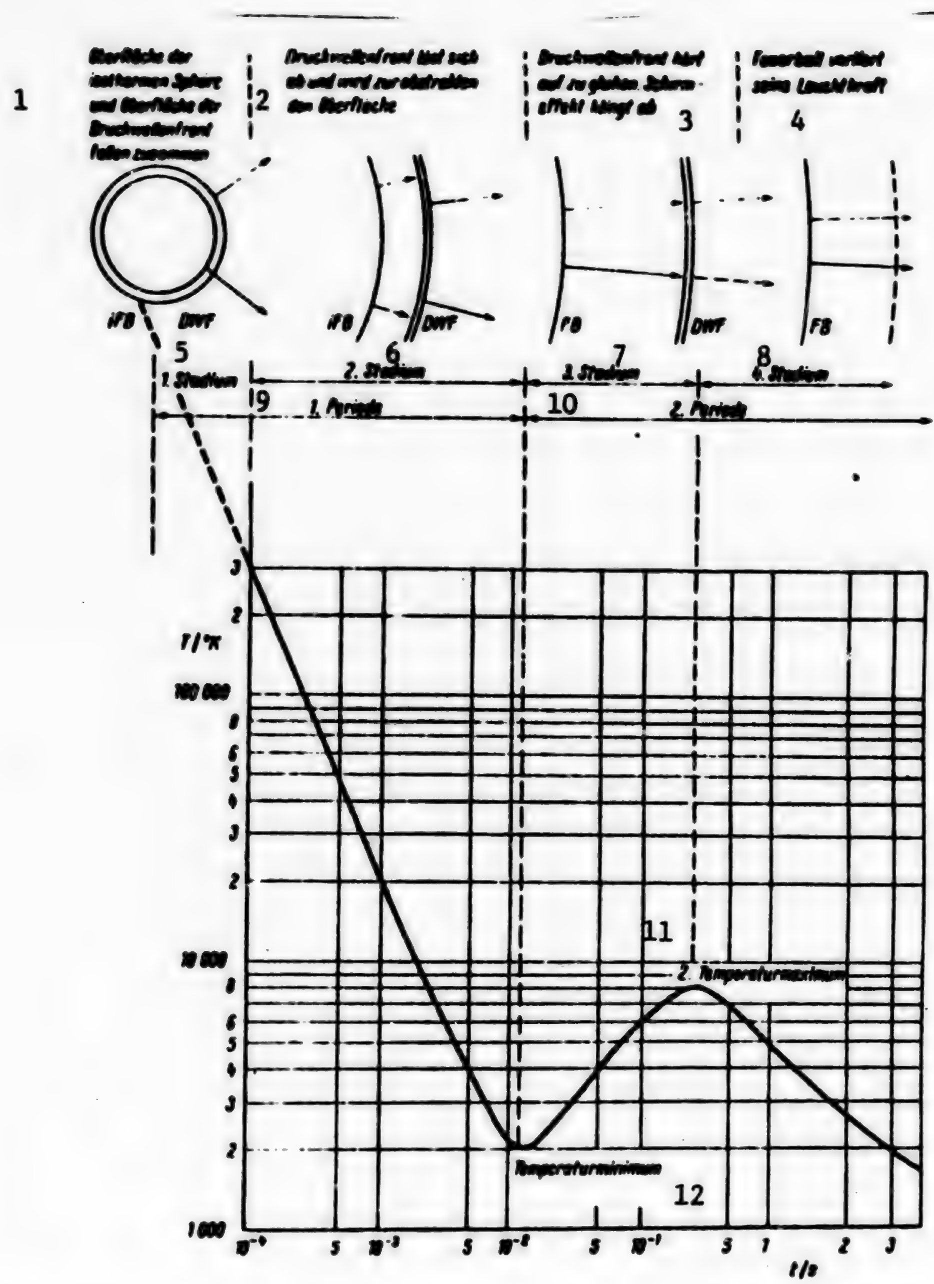


Figure 2.1. Diagram illustrating the development of the fireball and the temperature curve at the surface of the particular effective sphere.
Key: 1--Surface of isothermal sphere and surface of blast wave front coincide; 2--Blast wave front separates and becomes radiating surface; 3--Blast wave front stops glowing, screening effect fades; 4--Fireball loses its illuminating power; 5--1st stage; 6--2nd stage; 7--3rd stage; 8--4th stage; 9--1st period; 10--2nd period; 11--2nd temperature maximum; 12--Temperature minimum; DWF--Blast wave front; iFB--Isothermal fireball.

During the first stage, the fireball represents an isothermal sphere; that is to say, a ball in which the temperatures are equally high everywhere. The expansion speed of the fireball and the speed of the blast wave are equal. Because of that, the surface of the fireball and the surface of the blast wave front coincide. As the fireball grows, the temperatures in the isothermal sphere drop. At a certain point in time after the detonation, by which time the temperature has dropped to about 300,000 °K, the blast wave front moves faster than the front of the isothermal sphere and the blast wave front is separated from the fireball.

This marks the beginning of the second phase.

The cause of the fact that, during this second stage, the energy equalization with the surrounding medium takes place faster by means of the blast wave than via light radiation--a phenomenon which seems to conflict with general experience--can be explained in a simplified manner in the following way.

As we know, the intensity and wavelength of the light quantums radiated by a glowing body depend on the temperature of the radiating surface, in this case, on the fireball's surface temperature. In the high temperatures present in the isothermal sphere, most of the photons are found in the outermost part of the UV spectrum range.

Because the absorption of the light quantums by the air components again grows as their wavelength decreases, it follows that light radiation during this stage of the fireball's development has only an extremely small average free path distance. Light with wavelengths of less than 186 nm is on the average completely absorbed in the air after only 0.01 cm. This explains both the slow transport and isothermal state of the fireball.

Because of the great pressure gradient and the resultant fast velocity of the blast wave front and the air in this front, the air is so heavily compressed that, due to the developing friction, it is heated to temperatures of more than 2,000 °K and is thus made to glow. The fireball now consists of two separate concentric areas; the inner, isothermal sphere, and the shining blast wave front. The shining blast wave front is impermeable for the light radiation emitted from the isothermal sphere and therefore in this developmental stage appears as radiating surface of the fireball. If we therefore look at the temperature curve at the particular visible shining ball surface, appearing as a fireball, then a temperature minimum is reached during this stage. This is the end of the first period of the fireball's development.

The third stage is characterized by the fact that the overpressure in the wave front declines rapidly as the blast wave spreads further. This means that the wave front stops shining and ceases to be the radiating surface of the fireball. Parallel to that, the surface of the glowing detonation products gradually again appears as the effective surface of the fireball. The surface temperature rises to a second maximum.

The subsequent fourth stage and thus the second development period finally are terminated by the fact that the fireball is further cooled due to expansion and energy radiation and is finally extinguished.

The characteristic magnitudes of the fireball from a nuclear weapon detonation in the atmospheric layer near the earth are determined by the detonation intensity and the detonation altitude.

The duration of the first period and the radius of the fireball grow as the detonation intensity increases while the temperature minimum, appearing at the end of this period, goes down, the greater the detonation intensity.

The duration of the first development period t_1 of the fireball can by way of approximation be calculated with the help of the following empirical formula:

$$t_1 = 3{,}2 \cdot 10^{-3} \cdot q^{1/2} \text{ s} \tag{2.1}$$

The fireball's radius, during the passage of time t_1, as a function of q, follows the relationship:

$$R_1 = 235 \cdot q^{0{,}21} \cdot t^{0{,}36} \text{ m} \tag{2.2}$$

whereby we must have $t < t_1$.

The temperature minimum at the end of the first period can be calculated as follows:

$$T_{min} = 4{,}5 \cdot 10^3 \cdot q^{-0{,}1} \text{ °K} \tag{2.3}$$

q--detonation intensity/kt; t--time since detonation/sec.

Both during the first period of its development and during its second period, the fireball differs more or less from a sphere as a function of the detonation conditions. Major differences appear between the horizontal and vertical dimensions especially in connection with smaller detonation intensities. In the literature therefore data for the second period are often related to a so-called "equivalent fireball," that is to say, to a fireball whose volume corresponds to that of the real fireball.

Table 2.1. Reference Values for the First Period of the Fireball from a Nuclear Weapon Detonation (1)

q/kt	t_1/ms	R_1/m	T_{min}/°K
1	3	35	4500
10	10	80	3500
50	22	150	3000
100	32	190	2800
500	70	340	2400
1000	100	440	2200
5000	230	790	2000

(1) The figures given in the table were calculated according to formulas 2.1 to 2.3. They apply to the undisturbed development of the fireball.

This problem complex plays a certain role specially in the determination of the detonation intensity of a nuclear weapon due to technical devices by means of the dimensions of the fireball as well as during the origin of the electromagnetic impulse. In this connection it might be pointed out that the fireball is illustrated by radar sets, at least when the fixed-target suppression is turned off.

The fireball's light duration (radiation time) can be determined approximately with the help of the following formula:

$$t_L = q^{1/3} \text{ s} \tag{2.4}$$

The fireball's radius during the second period, that is to say, during time t_2, as a function of q, follows the relationship:

$$R_{equ} = 93{,}5 \cdot q^{0{,}38} \cdot t^{0{,}17} \text{ m} \tag{2.5}$$

whereby we must have $t_1 < t \leqq t_L$.

Table 2.2. Reference Figures for the Second Period of the Fireball from the Nuclear Weapon Detonation(1)

q/kt	t_L/s	R_{equ}/m
1	1,0	90
10	2,2	200
50	3,7	350
100	4,6	440
500	7,8	750
1000	10	950
5000	17	1650

(1) The numbers apply to an undisturbed fireball development.

The fireball is deformed at the end of the second period. Its horizontal dimension then is about 2.5 R_{equ}.

The illuminating power of the fireball depends little on the detonation intensity. This is due to the fact that the brightness is a function of the surface temperature which rises only relatively slowly as the detonation intensity grows.[3]

The detonation altitude essentially influences the shape of the fireball and thus also its dimensions. At detonation altitudes of $H_D > 100 \cdot q^{1/3}$ m the fireball has a spherical shape. Starting at $H_D < 100 \cdot q^{1/3}$ the fireball increasingly takes on the shape of a hemisphere, that is to say, it is flattened out at its underside. At a detonation altitude of $H_D < 35 \cdot q^{1/3}$ m, the fireball finally touches the ground.

At H_D = 0 m we speak of a contact detonation where the fireball initially is completely hemispherical but then it immediately extraordinarily deforms. The detonation altitude, at which the fireball from a nuclear weapon detonation of a certain intensity touches the ground, cannot simply be determined by comparison with the particular maximum fireball radius.

This is due to the fact that the fireball reaches its maximum extent only during a certain period of time, that it moves upward at the same time while it spreads out, and that it is furthermore flattened out along its underside by the blast wave which is reflected along the earth's surface. It is generally assumed that no contact takes place between the fireball and the earth's surface with a high degree of certainty if the detonation altitude at least corresponds to the size of the fireball's radius at the time of the second temperature maximum ($t(T_{max}) = 0.065 \cdot q^{t/3}$ s). According to Schrader[4] the following empirical formula then applies to the dependence between the fireball's radius according to Formula 2.5 when $t = t\,(T_{max})$ and the detonation intensity q:

$$\frac{R_1}{R_2} = \left(\frac{q_1}{q_2}\right)^{2/5} \qquad (2.6)$$

Further considerations regarding the fireball can be found in Section 4.1 in connection with the treatment of the general characteristic of the destruction factor which we call light radiation.

2.1.2. Detonation Cloud

A cloud characteristic of the particular detonation type is formed a few minutes after a nuclear weapon detonation.

The radioactive detonation cloud has the shape of a mushroom during detonations in which the fireball at least partly reaches the atmosphere. It consists of the detonation cloud as such (the condensation cloud) and the stem which is formed of earth and slag or water masses that are whirled upward.

The detonation cloud is formed from the fireball which gradually becomes colder due to enlargement and energy radiation. Depending on the type of detonation, it consists mostly of the condensed wreckage of the nuclear weapon, including the radioactive detonation products, atmospheric dust, and vaporized as well as unvaporized ground material or water. It is typical of this condensation cloud that it above all contains small and very small particles (aerosols). The quantity and type of soil material (water), which is swept upward by the suction effect hose that is formed due to the fast climbing speed of the fireball, depend on the detonation intensity, the detonation altitude or depth, and the nature of the detonation area. Here we are dealing primarily with large and larger particles which, after detonation, rapidly fall back into the detonation area and its immediate vicinity.

Because the radioactive detonation products in fact are to be found exclusively in the condensation cloud, the character of the terrain's radioactive

contamination following a nuclear weapon detonation depends decisively on the extent to which the smoke or dust column, or water column, forming the stem, is blended or mixed with the condensation cloud (see the descriptions in sections 2.2.2 and 7.2.2).

According to data from Lapple[5], the steadily rising detonation cloud $2.5 \cdot 10^{-4}$ t nuclear weapon fragments, $2.5 \cdot 10^{-2}$ t atmospheric dust, 12 t vaporized and $1.2 \cdot 10^{3}$ t unvaporized soil material per km^3 on the average following a surface burst (contact detonation).

The most important characteristic features of the detonation cloud, in addition to its shape, are the climbing height as well as its vertical and horizontal extent.

These magnitudes are primarily determined by the detonation intensity, the detonation altitude, the meteorological conditions, and the nature of the detonation area.

The dimensions of the detonation clouds and their climbing altitudes grow as the detonation intensity increases. The maximum climbing height is a function of the "thermal value" of the particular nuclear weapon; that is to say, the rise of the detonation cloud is finished when the average temperature of the cloud has become adjusted to that of the environment due to heat transfer resulting from expansion, mixing, and radiation. Similar aspects apply to the horizontal extent.

The mushroom shape of the cloud is caused by the fact that the temperature differences between the inner and outer surfaces cause a toric circulation whereby the colder air masses slide from top to bottom along the outside surfaces.

A detonation cloud is in the so-called "stabilized state" if, in comparison to the environment, the temperature and pressure conditions are essentially in balance. After that point in time, especially in detonations in the megaton range, the detonation cloud however can experience a further horizontal expansion.

Accordingly, Fuchs[6] describes the state, attained due to the detonation cloud after the complete termination of toric circulation, as "initial state" and says that this state is attained after 4-6 min for detonation intensities of 1-10 kt, after 6-10 min for intensities of 10-300 kt, after about 10 min for 300-1,000 kt, and after 10-20 min when $q > 1{,}000$ kt.

The climbing speed, like the climbing altitude, depends on the detonation intensity. The greater the detonation intensity, the faster will the cloud rise and reach the stabilized state.

Wilckens[7] reports that, following a nuclear weapon detonation with $q = 1$ Mt, the average rising velocity during the first minute is 400 km hr^{-1} (110 m sec^{-1}) whereas after 4 min it is still more than 100 km hr^{-1} (30 m sec^{-1}).

At q = 1 kt, the detonation cloud thus reaches its maximum average climbing height of 3,600 m in about 9 min; at q = 1 Mt, it reaches the corresponding height of 21,700 m already in about 7 min.

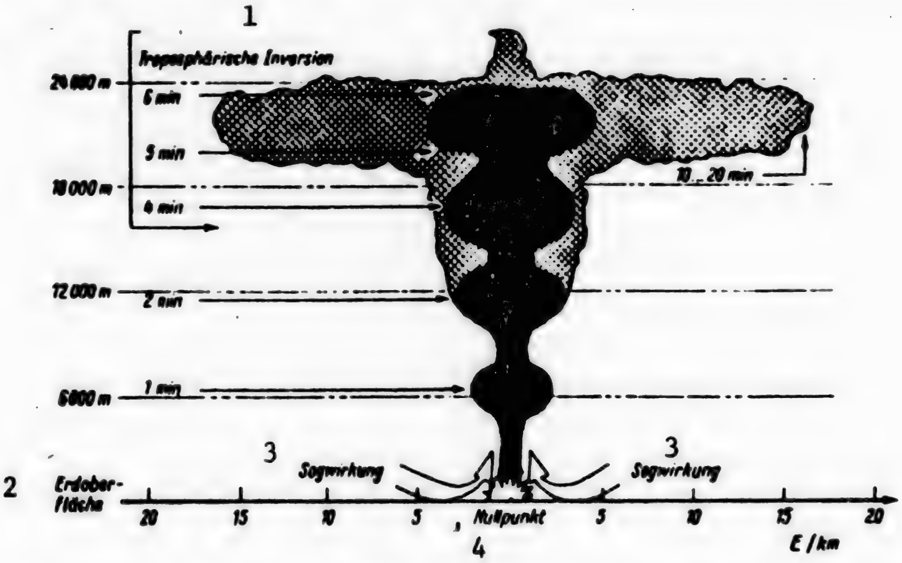


Figure 2.2. Diagram illustrating the development of the detonation cloud from a nuclear weapon detonation with an equivalent of 1 Mt:[8]
Key: 1—Tropospheric inversion; 2—Earth's surface; 3—Suction effect; 4--Measurement point.

The dimensions of the detonation clouds for air and surface bursts can be determined with the help of the approximation formulas assembled by Fuchs with the help of a balancing computation.[9] The values determined in this fashion reveal agreement with analogous data in other bibliographic reference sources.

The following applies for the climbing height (cloud center)
For detonation intensities of $1 \leq q < 50$ kt

$$H_{SM} = 3170 \cdot q^{0.31} \text{ m} \tag{2.7}$$

For detonation intensities of $50 \leq q \leq 10000$ kt

$$H_{SM} = 4860 \cdot q^{0.19} \text{ m} \tag{2.8}$$

For the upper and lower cloud boundary $\overline{H}$ or $\underline{H}$ we get the following as a function of the detonation intensity:

For detonation intensities $1 \leq q < 50$ kt

$$\overline{H} = 3595 \cdot q^{0.31} \text{ m} \tag{2.9}$$

$$\underline{H} = 2745 \cdot q^{0.31} \text{ m} \tag{2.10}$$

For detonation intensities $30 \leq q \leq 10000\,kt$

$$\bar{H} = 4860 \cdot q^{0.19} + 425 \cdot q^{0.31} \quad m \qquad (2.11)$$

$$\underline{H} = 4860 \cdot q^{0.19} - 425 \cdot q^{0.31} \quad m \qquad (2.12)$$

Some values calculated on this basis are compiled in Table 2.3.

Table 2.3. Average Values for the Maximum Dimensions of Detonation Clouds from Surface Bursts (1)

q kt	1 obere Grenze m	2 untere Grenze m	3 Durchmesser m	4 Steigzeit min
1	3600	2700	2000	9
10	7300	5600	4500	9
50	11600	8800	7000	9
100	13400	9900	9000	9
500	18700	12900	16000	7,5
1000	21700	14400	20000	7
5000	30500	18600	34000	5

Key: 1—Upper limit; 2—Lower limit; 3--Diameter; 4--Climbing Time;
(1) Deviations on the order of magnitude of ±20 percent from the numerical values given must be considered normal. In case of air bursts, it is necessary to add the detonation altitude to determine the upper and lower cloud boundaries.

In the case of air bursts in the atmospheric layer near the ground, the detonation altitude only has a minor effect on the detonation cloud formation process, apart from the increase in the climbing height. The cloud's climbing speed is practically completely independent of the detonation altitude.

The situation is different in the case of surface and underground bursts.

It was pointed out earlier that--concerning the problem complex of radioactive terrain contamination--the degree of merger between the stem and the condensation cloud plays a big role. This process can be considered a function of the detonation altitude.

In case of detonations at an altitude of $H_D > 200 \cdot q^{1/3}$ m there is no merger of the dust column with the actual detonation cloud.

Starting at detonation altitudes of $H_D < 200 \cdot q^{1/3}$ m such a merger does take place and it will be all the more intensive, the lower the nuclear weapon explodes.

This finally leads to a situation where, following surface bursts, there is an immediate mixing of the radioactive detonation products with the slag or earth masses that are vaporized or melted out by the fireball and that are expelled by the blast wave.

For example, in the case of surface bursts of Mt--if one assumes that 5 percent of the energy are consumed to melt the ground out--an additional about 20,00 t of earth mass get into the fireball or the detonation cloud.

In the case of underground bursts, a certain part of the detonation energy remains in the ground; this is why the detonation clouds reach lesser climbing heights than after surface bursts. The greater the detonation depth, the smaller the climbing heights. They can roughly be determined from the values of the climbing heights deriving from surface bursts (Table 2.3) with the help of the following empirical formula:

$$H_{St\,(UD)} = H_{St\,(ED)}\,(1 - 0{,}01\,H_r) \qquad (2.13)$$

$H_{st\,(ED)}$--Maximum climbing height of detonation cloud after surface burst of equivalent intensity/m.
H_r--absolute amount of reduced detonation or placement depth/m.

The reduced placement depth can be calculated from the following relation:

$$-H_r = -H_{qkt} : q^{1/3} \qquad (2.14)$$

$-H_r$--reduced placement depth/m

$-H_{qkt}$--Specific placement depth of nuclear charge with intensity q kt/m.
q--Detonation intensity/kt.

The detonation cloud's formation is essentially influenced by the temperature stratification in the atmosphere. The location of the tropopause is particularly important. As an inversion layer, the tropopause decisively influences the cloud's climbing height and climbing speed.

In detonations where $q \leq 50$ kt we may assume that the detonation cloud will not break through the tropopause. In this detonation intensity range the cloud spreads mostly horizontally on reaching the underside of the blocking layer.

In detonations where $q > 50$ kt the tropopause is penetrated. After detonations in the megaton range, the entire cloud takes shape in the stratosphere.

The position of the tropopause depends on the geographic latitude, the season, and the macrometeorological situation. The boundary layer between the troposphere and the stratosphere is at an altitude between 8 km and 18 km whereas in our middle latitudes it is between 8 km and 12 km. The tropopause represents the transition from the temperature which in the troposphere decreases on the average with the altitude and the almost constant temperature in the lower stratosphere. Because the tropopause in the summer is generally higher than in the winter, we get greater climbing heights as a result of that from the corresponding detonation intensities.[10]

During the detonation of a nuclear weapon in the atmospheric layer near the ground, the detonation cloud initially has a more or less reddish-brown color. The developing nitrogen compounds are responsible for this. The cloud takes on a whitish color with the start of water vapor condensation.

The coloring of a cloud deriving from a nuclear weapon detonation in the atmosphere can be used to determine the detonation type, although only with restrictions, because it depends heavily on the meteorological conditions in the particular specific case.

Certain definite conclusions however can be drawn from the shape of the cloud. This applies above all to underground and underwater detonations. In the first case, for example, the entire cloud is not only dark in color but there is likewise no formation of the otherwise characteristic mushroom shape. Further statements on this problem complex can be found in Section 2.2.2. during the description of the individual detonation types.

2.1.3. Detonation Crater

A detonation crater is formed in the area of ground zero after surface and underground bursts. The dimensions and shape of this crater in particular depend on the detonation altitude or depth, the detonation intensity, as well as the geological nature of the detonation area.

The detonation crater originates due to the effect of light radiation (fireball) and the blast wave upon the soil; that is to say, due to evaporation, melting, expulsion, and condensation of the ground.

The detonation crater is extremely radioactive.

In case of detonations in the ground, we must distinguish between detonations with external and internal effects. In case of detonations with external effects, an open crater is formed whereas in detonations with internal effect, the detonation does not break through the earth's surface and we thus get an underground, enclosed cavity.

Detonations with external effect are of particular military interest. As a result of the analysis of a larger number of experimental detonations involving nuclear charges and chemical explosives it became possible to work out reference figures concerning crater formation. The descriptions in this section are based above all on investigations by Nifontov.[11]

Certain characteristic crater elements can be distinguished in the individual detonations regardless of the detonation intensity and the detonation altitude (depth). They are illustrated in Figure 2.3.

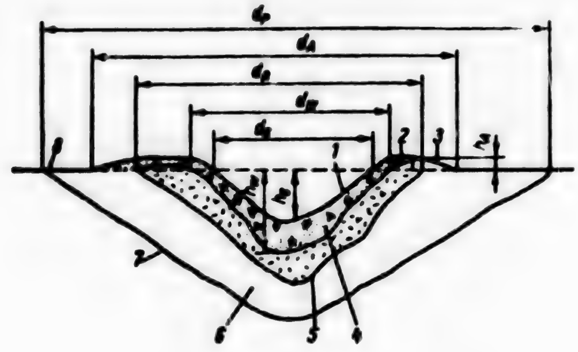


Figure 2.3. Illustration of the most important elements of the detonation crater deriving from surface and underground detonations. 1--Visible crater; it is formed due to the expulsion of earth and slag masses and the fact that they partly fall back into the real crater; 2--The real crater; it encompasses the crater dimensions according to the original ejecta; the visible crater and the real crater in terms of their shape are more or less heavily reminiscent of a paraboloid; 3--The crater edge; it is formed all around the crater by the ejected dirt and slag masses; 4--Dirt and slag layer covering the bottom of the real crater; 5--Crevice formation zone; it borders directly on the real crater; the floor reveals severe cracks and gaps and is partly ground up; 6--Zone of plastic deformation; it comes right after the crevice formation zone and covers an area in which the floor is irreversibly shifted; in this bottom layer however we do not have any externally visible features (for example, cracks); because of the heavy compression of the ground, solid surface or underground structures are completely destroyed or heavily damaged; in case of detonations in rocky ground, the zone of plastic deformation is completely missing or it is just about completely missing; 7--Zone of elastic deformation; it follows right after the zone of plastic deformation and covers the entire area of the ground in which heavily seismic detonation clouds spread; its magnitude and shape are greatly influenced by the geological structure of the detonation area; in this zone likewise we can expect destruction due to severe concussions in a certain radius; 8--Earth's surface; d_S--Diameter of visible crater; h_s--Depth of visible crater; d_W--Diameter of real crater; h_W--Depth of real crater; d_A--Diameter of filler zone; h_A--Height of crater pile-up; d_R--Diameter of crevice formation zone; d_P--Diameter of plastic deformation zone.

In the case of ground bursts--strictly speaking, in the case of contact detonations--one can also express the relations between the individual magnitudes with the help of the following approximation formulas:

$$d_A \approx 2 \cdot d_s \pm 25\% \qquad (2.15)$$

The maximum height of the crater material pileup is as follows:

$$h_A \approx 0.25 \cdot h_s \pm 50\% \qquad (2.16)$$

The diameter of the crevice formation zone is determined as follows:

$$d_R \approx 1{,}5 \cdot d_s \pm 25\% \qquad (2.17)$$

For the diameter of the plastic deformation zone, we may assume the following:

$$d_P \approx 3 \cdot d_s \pm 50\% \qquad (2.18)$$

The volume of ejecta (crater size) can be calculated as follows

$$V_T \approx \Pi \frac{d_s^2 \cdot h_s}{8} \qquad (2.19)$$

If the formulas given are to be used for the determination of analogous values from underground detonations, this must remain confined to detonations with shallow placement depth. In this case however we get greater degrees of uncertainty than given above.

At this point there is no need for any more detailed explanation of the fact that, other detonation conditions being equal, the crater dimensions are essentially determined by the geological soil structure. The formulas given above apply to sandy and clayey soils. Correction factors must be used for other soil conditions. In case of detonation near the surface in rocky ground (granite, limestone, sandstone), the crater diameters and the crater depths (factor of 0.8) are reduced; in case of water-saturated soils, the values of the correction factors are 1.7 for the diameter and 0.7 for the depth.

Nordyke[12] among other things observes that, in case of detonations in rocky underground, the crater dimensions are reduced by about 20–30 percent whereas in detonations in wet soils the dimensions are 20–50 percent greater than in dry sandy and clayey soils.

It is furthermore not enough to use only the upper soil layers as basis in judging the possible crater formation and the other effects. Instead, a knowledge of the deeper soil structure is also necessary for that.

For example, in the reflection of the blast wave along deeper situated rock layers and its repeated reflection along the earth's surface, a soil layer several tens of centimeters thick is lifted off in the case of sandy and clayey soil.

The dimensions of the detonation crater grow as the detonation intensity increases. In sandy and clayey soils we may assume in the case of contact detonations that, at a detonation intensity of $q = 1$ t the crater diameter with $d_s = 35$m and the crater depth will be $h_s = 6$ m. These values have a degree of uncertainty of ± 25 percent.

For detonation intensties of $q \neq$ kt we can find the corresponding values with the help of the analogy laws.[13]

The analogy laws make it possible to compare the change in the linear crater dimension (diameter and depth) as a function of the change in the detonation intensity or the detonation depth or two detonations with equivalents q_1 and q_2.

In the most general form, they can be formulated as follows:

$$\frac{d_1}{d_2} = \left(\frac{q_1}{q_2}\right)^{x_d}; \frac{h_1}{h_2} = \left(\frac{q_1}{q_2}\right)^{x_e}; \frac{H_1}{H_2} = \left(\frac{q_1}{q_2}\right)^{x_H} \qquad (2.20)$$

d—Diameter of crater; h—Crater depth; H—Detonation or placement depth; q—Detonation intensity.

For the exponential coefficients x_d, x_e, and x_H literature sources generally suggest the value 1/3 or, more exactly, 1/3.4.[14]

On the basis of the crater formation values given following the ground burst (contact detonation) with q = 1 kt, we get the analogy laws as follows:

$$d_s = 35 \cdot q^{\frac{1}{3.4}} \text{ m} \qquad (2.21)$$

$$h_s = 6 \cdot q^{\frac{1}{3.4}} \text{ m} \qquad (2.22)$$

The values calculated according to this formula are compiled in Table 2.4.[15]

In addition to the factors covered here, the detonation altitude decisively influences the crater formation.

Table 2.4. Reference Values for Crater Formation after Contact Detonations in Sandy and Clayey Soils as a Function of the Detonation Intensity(1)

1 Detonationsstärke kt	2 Trichterausmaße m, 3 Durchmesser	Tiefe 4
1	35	6
10	75	12
50	130	20
100	160	25
500	280	45
1000	350	60
5000	600	100

Key: 1—Detonation intensity; 2—Crater dimensions; 3—Diameter; 4—Depth; (1) Correction factors must be used for other soil conditions.

In case of nuclear weapon detonations at altitudes $H_D < 100 \cdot q^{1/3}$ m, there will be cracks in the earth in the area of ground zero in sandy and clayey soils within a radius of several hundred meters.

Starting with a detonation altitude of $H_D < 35 \cdot q^{1/3}$ m, the ground will melt in the immediate area around ground zero.

We can expect a crater formation of the kind described above starting with a detonation altitude of about $H_D < 15 \cdot q^{1/3}$ m.

In case of underground detonations, the crater dimensions vary with the detonation depth. Here again we can draw similar conclusions on the basis of analogy laws.

Figure 2.4 illustrates the crater dimensions as a function of the detonation depth for sandy and clayey soils and for a detonation intensity of 1 kt. The folowing rough calculations are necessary for the determination of the crater dimensions following a detonation intensity of $q \neq 1$ kt:

(a) The detonation depth given $-H_D$(m) following detonation intensity q(kt) is converted to the reduced detonation depth $-H_r$(m) for 1 kt.

$$-H_{r(1\,kt)} = \frac{-H_{q\,kt}}{q^{\frac{1}{3.4}}} \quad \text{m} \tag{2.23}$$

(b) For the calculated value $-H_{r\,(1\,kt)}$ the crater radius and the crater depth can be read off from Figure 2.4.

(c) The crater diameter and the crater depth for detonation intensity q can then be calculated as follows:

$$d_{s(q\,kt)} = 2r_{s(1\,kt)} \cdot q^{\frac{1}{3.4}} \quad \text{m} \tag{2.24}$$

$$h_{s(q\,kt)} = h_{s(1\,kt)} \cdot q^{\frac{1}{3.4}} \quad \text{m} \tag{2.25}$$

(See footnote 17).

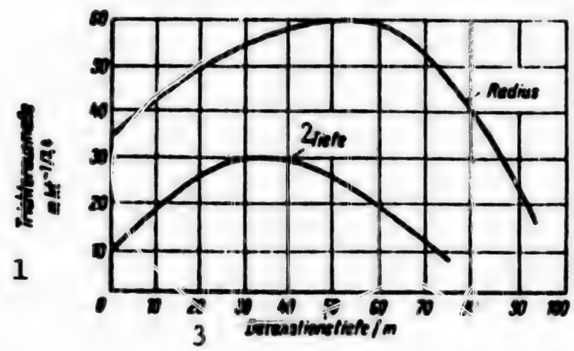


Figure 2.4. Change in crater dimensions following underground detonation of q = 1 kt as a function of the detonation depth.[16] Key: 1--Crater dimensions; 2--Depth; 3--Detonation depth/ m.

Table 2.5. Crater Dimensions Following Underground Detonations in Sandy and Clayey Soils as a Function of the Detonation Intensity and Depth.(1)

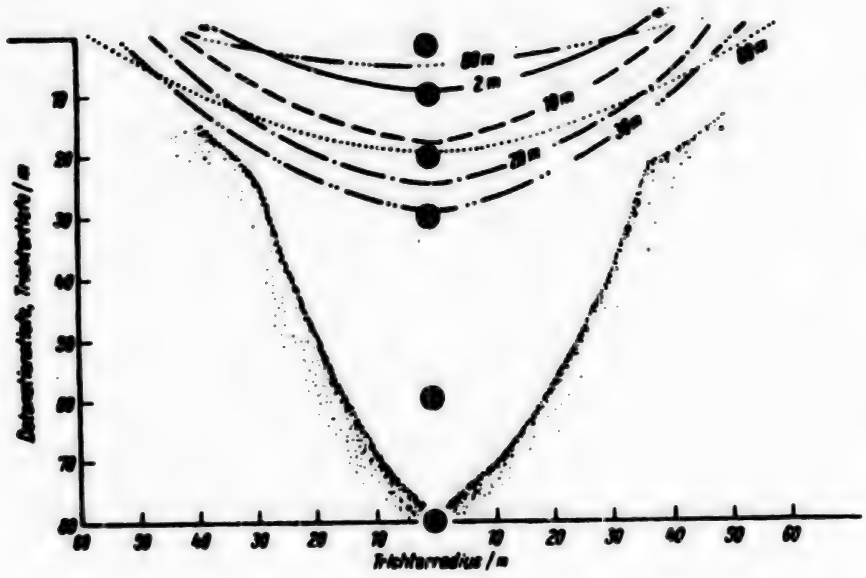
q/kt	Detonationstiefe/m[1]									
	10	20	30	40	50	60	70	80	90	100
0,1	50	60	55	40						
	13	15	10	2						
0,5	70	85	90	100	95	75				
	16	23	24	21	16	7				
1	85	95	110	115	120	120	105	80	22	
	18	25	29	29	26	20	12	[illegible]	–	
2	100	115	125	135	145	150	145	140	120	46
	21	29	34	36	36	32	27	19	12	7
5	125	140	155	165	175	185	190	195	195	190
	25	34	40	45	48	48	46	42	36	29
8	145	160	170	185	190	205	210	220	220	225
	28	36	44	49	53	55	55	53	49	43
10	150	165	180	195	205	215	220	230	235	240
	29	38	45	51	56	58	59	57	55	50
20	180	200	210	225	240	250	260	270	280	285
	34	42	50	58	63	68	71	72	72	70
30	205	220	235	250	260	270	285	290	305	310
	37	46	54	61	68	73	77	80	81	81
50	235	250	265	280	290	305	320	330	340	350
	41	50	59	67	74	80	85	89	92	94
100	285	300	315	330	345	360	370	380	395	405
	48	57	66	75	82	90	96	101	106	110

Key: 1--Detonation depth/m; (1) The upper number in each case indicates the diameter and the lower number gives the depth of the detonation crater in meters.

In order better to illustrate the crater formation deriving from underground detonations as a function of the detonation depth, Figure 2.7 illustrates the change in the crater dimensions for a nuclear weapon detonation of q = 1 kt.

For each detonation intensity there is an optimum detonation depth in connection with underground detonations. By that we mean the depth at which the visible crater reaches its maximum volume.

1



2

Figure 2.7. Greatly simplified illustration of crater formation after underground detonation of q = 1 kt as function of detonation depth. Key: 1--Detonation depth, crater depth, m; 2--Crater radius, m.

The corresponding values can be determined according to the following empirical formulas:

$$-H_{opt} = 30 \cdot q^{\frac{1}{3.4}} \quad \text{m} \tag{2.26}$$

$$d_{opt} = 122 \cdot q^{\frac{1}{3.4}} \quad \text{m} \tag{2.27}$$

$$h_{opt} = 27 \cdot q^{\frac{1}{3.4}} \quad \text{m} \tag{2.28}$$

Formula 2.26 shows that the nuclear charge must be placed very deep to get optimum crater formation. This among other things points to the conclusion that small and medium detonation intensities are above all suitable for nuclear mines. Greater detonation intensities can hardly be ignited at the optimum detonation depth, as we can see from the draft (Figure 2.8).

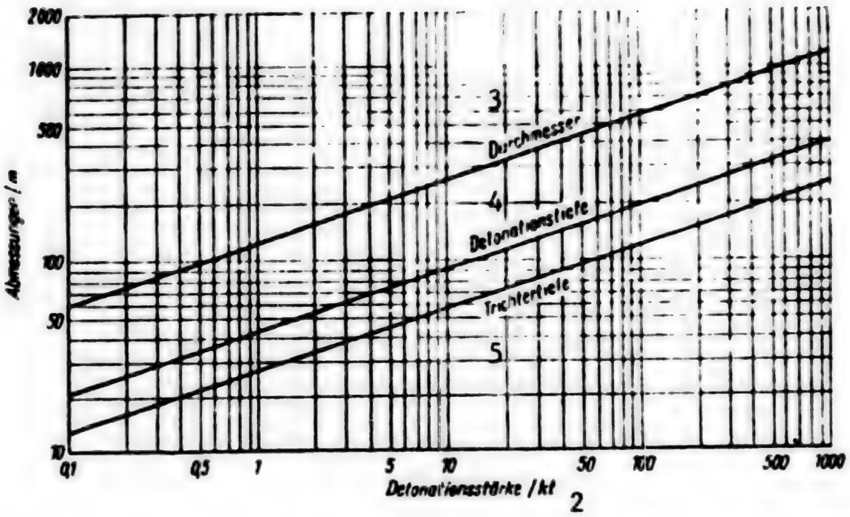


Figure 2.8. Optimum detonation depths and the resultant maximum crater dimensions for alluvial soils as a function of the detonation intensity.[18] Key: 1--Dimensions, m; 2--Detonation intensity, kt; 3--Diameter; 4--Detonation depth; 5--Crater depth.

In general we can observe that, in the case of underground detonations at optimum depth, the diameter of the crater is about 3 times bigger and the depth is about twice bigger than in detonations near the surface.

In rocky soil, the optimum detonation depths are on the average 20 percent above the values for sandy and clayey soils.

As a function of the detonation intensity and the geological structure of the detonation area, the earth's surface is no longer penetrated, starting at a certain detonation depth. In this case we speak of nuclear detonations with a completely internal effect.

Table 2.6. Reference Values for Optimum Crater Formation after Underground Detonations in Rocky Soil with Various Detonation Intensities

1	Detonationsstärke/kt				
	0,1	1	10	100	1000
$-H_{opt}$/m	15	35	70	160	320
d_{opt}/m	50	95	220	440	950
h_{opt}/m	10	20	50	100	200

Key: 1--Detonation intensity, kt.

The typical phenomena of such a detonation are illustrated by Nifontow using the example of the American "Rainier" test blast on the Nevada test range.[19]

The "Rainier" test is an underground detonation with an equivalent of 1.7 kt TNT, ignited in a tufa massif at a depth of 274 m. (See Figure 2.9 in conjunction with the explanations given below.)

As a result of the detonation, a cavity with a diameter of 30 m (1) was formed originally. This cavity however collapsed and was filled with rock.

Regarding the destruction or deformation of the rock, it was possible to distinguish two destruction areas in a heavily simplified fashion.

The first area encompassed a central hemispherical zone around the detonation center with a thickness of about 20 m (2). It was formed by the immediate effect of the blast wave upon the rock surrounding the nuclear charge. Here the rock was in a heavily deformed and compressed state. The rock compression in the lower part of the zone was greater than in the upper part. The crack formation zone (3) followed next, going toward the outside, with a thickness of about 50 m. The zone of plastic deformation (4) began at a radial distance of 90 m.

The second destruction area encompassed the zone of fractured rock (5). It began below the original detonation point and extended in the form of a cylinder or truncated cone up to the upper limit of the destruction area. A small cavity with a diameter of 7 m (6) developed along the upper boundary of the fracture cone. The rock in the fracture zone was heavily smashed. The size of the rock fragments fluctuated between diameters of several decimeters in the peripheral region up to meters in the area below the original nuclear charge. The areas between the rock chunks were filled with pulverized and partly again hardened rock material.

The fracture cone reached a total height of 120 m. Smaller cracks and gaps formed in the fracture zone in the rock (7).

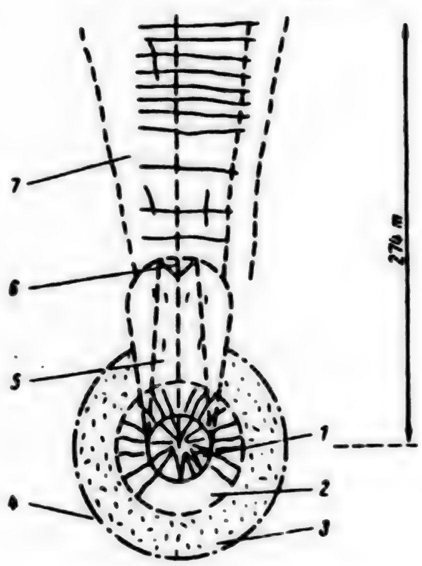


Figure 2.9. Rock deformation zones folowing "Rainier" test detonation.

Analyzing the various test detonations, we can estimate that, in case of detonations with a completely internal effect, in tufa massifs, per kt of detonation energy, about 300,000 t (135,000 m^3) of rock are destroyed in the area of the compression zone and about 120,000 t (53,000 m^3) or rock are destroyed in the area of the fracture zone.

Under identical geological conditions one may furthermore assume that the diameters of the developing cavities d_H and the diameters of the compression zones d_v in case of two equivalent detonations of q_1 and q_2 behave like:

$$\frac{d_{H_1}}{d_{H_2}} = \frac{d_{v_1}}{d_{v_2}} = \left(\frac{q_1}{q_2}\right)^{\frac{1}{3.4}} \tag{2.29}$$

As criterion for a nuclear weapon detonation with a completely internal effect we can take the minimum necessary detonation depth or "line of least resistance" for tufa as follows:

$$-H_{min} = 120 \cdot q^{\frac{1}{3.4}} \quad m \tag{2.30}$$

Up to detonation depths of:

$$-H_0 \approx 95 \cdot q^{\frac{1}{3.4}} \quad m \tag{2.31}$$

We can expect significant destruction along the earth's surface.

Review Questions

2.1. How can we explain the fact that the blast wave front is separated from the isothermal sphere during the fireball's second development stage?

2.2. How can we explain the origin of the second temperature maximum in the fireball's development.

2.3. How do the detonation intensity and detonation altitude influence the size and shape of the fireball?

2.4. According to what rough formula can we draw conclusions regarding the detonation intensity from the illumination time of the fireball?

2.5. Explain the process of detonation cloud formation.

2.6. What are the factors that essentially determine or influence the dimensions, climbing heights, and shapes of detonation clouds?

2.7. Why does the character of radioactive terrain contamination essentially depend on the degree to which the stem and the condensation clouds are merged?

2.8. What does the heavy influence of the tropopause on the maximum climbing height of the detonation cloud result from?

2.9. Under what conditions will a crater be formed after nuclear weapon detonations?

2.10. List and explain the most essential crater elements following ground and underground bursts.

2.11. What are the factors that influence the detonation crater's shape and size?

2.12. What do we mean by the concept of "reduced detonation depth?"

2.13. Explain the concept of optimum placement or detonation depth.

2.14. Under what conditions can underground detonations heavily influence combat operations by military units?

2.2. Types of Nuclear Weapon Detonation

2.2.1. Destruction Factors Deriving from Nuclear Weapon Detonation

The energy released as a result of a nuclear weapon detonation takes effect in various forms of energy such as pressure, light (heat), radioactivity, and electromagnetic impulse.

On this basis we distinguish four fundamental annihilation factors:

Blast wave;

Light radiation;

Instant nuclear radiation;

Residual nuclear radiation.

In this connection we will cover the electromagnetic impulse--which in the literature is described sometimes as the fifth annihilation factor--later on because it recedes far into the background regarding the overall effect of the above-mentioned annihilation factor.

Out of the total energy released, about 85 percent take effect immediately at the moment of detonation in the detonation area and in its immediate vicinity. The remaining 15 percent consists of the residual nuclear radiation of radioactive terrain which, in terms of its effect, is confined not only to the detonation area but which can cover larger terrain sectors in the direction in which the radioactive detonation cloud moves off.

The distribution of detonation energy over the individual annihilation factors is not constant but is influenced by the detonation intensity, the type of nuclear weapon, the detonation altitude, and the nature of the detonation area.

Following the detonation of nuclear weapons in the kiloton range in the atmospheric layer near the earth, we have the following percentages out of the total energy:

Blast wave: 40-50%,
Light radiation: 30-40%,

Instant nuclear radiation: 4-5%,
Residual nuclear radiation: 15%.

In this kind of estimate however one must keep in mind that this detonation energy distribution is not directly reflected in the same fashion in terms of damage or casualties deriving from a nuclear weapon detonation because the character of the particular detonation area or the target hit is of decisive significance.

The blast wave deriving from a nuclear weapon detonation can spread in the air, in the ground, and in water. Its annihilating and destructive effects are based primarily on the maximum overpressure along the blast wave front and the fast movement speed or acceleration of the air, the water, or the soil in the wave front.

The most important parameters of the blast wave are the overpressure in the wave front, the speed of the air masses which are moved in the wave front, as well as their density and temperature. Compared to conventional detonations, the developing overpressure values are not only considerably higher but the blast wave deriving from a nuclear weapon detonation also has a considerably greater depth and action time.

Light radiation (thermal radiation, heat radiation) is an electromagnetic radiation in the wave range from 5 mm to 0.1 mm. The share of energy contained in the individual spectrum ranges (UV, visible, IR) among other things change as a function of the detonation intensity.

The light radiation deriving from a nuclear weapon detonation causes fires and in man leads to burns and blinding.

The most important parameters of light radiation are the size of the light impulses appearing at the particular distances and their [illegible]tion duration.

Instant nuclear radiation consists of a flow of neutrons and gamma quantums of high energy. By definition, it is radiated within a span of time of up to 1 min after the detonation from the radioactive detonation products in the detonation cloud. The corpuscular neutron flow and the electromagnetic gamma radiation in man and in other living beings leads to radiation injuries or radiation sickness in case of corresponding radiation doses. The neutron flow furthermore leads to the formation of radioactive nuclides.

The most important parameters of instant nuclear radiation are the energy and intensity of the neutrons and gamma quantums.

Residual nuclear radiation consists of electromagnetic gamma radiation as well as corpuscular alpha and beta radiation from radioactive detonation products.

The radioactive contamination of the terrain caused by a nuclear weapon detonation can have a local, continental, and global character. Troops operating in radioactively contaminated areas can be harmed by high doses of residual nuclear radiation and by the incorporation of radioactive substances.

The most important parameters of residual nuclear radiation are its energy, intensity, and action duration.

2.2.2. Detonation Type as Function of Detonation Altitude

All effects springing immediately from a nuclear weapon detonation are terminated in case of detonations with an equivalent of $q < 500$ kt within 1 min and in case of $q > 500$ kt within 3 min.

The annihilation factors basically described in the preceding section appear in all nuclear weapon detonations. Their specific effectiveness however is directly determined by the specific facts involved in the particular detonation. Other things being equal, the character of a nuclear weapon detonation is decisively shaped by the place and by the detonation altitude or depth.

Depending on the detonation intensity, the detonation type is a function of the detonation altitude. It characterizes the specific conditions of a nuclear weapon detonation and thus describes the qualitative and, to a certain extent, also the quantitative effect of the developing annihilation factors.

Along with the change in the detonation altitudes, the detonation types are blended with each other, without any sharp dividing lines.

The type of detonation of nuclear weapons which can be used by the enemy in combat or in course of other operations will particularly depend on the general battlefield situation, the type and manner of mission to be accomplished, the character of the target to be engaged, the degree of intended destruction, the terrain relief, and the weather conditions.

For each type of detonation there is a characteristic detonation altitude range in which the specific properties of the corresponding detonation will be most pronounced. Between these altitude ranges there are boundary cases in which the character of the detonation cannot be clearly defined.

This is why--regardless of the detonation altitudes or altitude ranges marking the individual detonation types--we distinguish so-called optimum detonation altitudes. The particular optimum detonation altitude depends on the detonation intensity and the target's character. A nuclear weapon detonation at such an altitude, with a given target characteristic, will lead to optimum destruction of annihilation; that is to say, to the maximum possible size of the destruction area.[20]

As a function of the detonation altitude or depth above or below the earth's surface or the water surface, we essentially distinguish the following detonation types:

Altitude burst
Air bursts

Ground bursts	Water bursts
Underground bursts	Underwater bursts

Altitude detonations are further subdivided into troposphere detonations, stratosphere detonations, ionosphere detonations, and cosmic detonations.

The following in particular depend on the altitude or the depth of a detonation:

The range of individual annihilation factors with a view to the annihilation or destruction of a certain target;

The character and size of the residual effects or after effects.

Here, the concept of after effects is supposed to mean the crater formation, the neutron-induced radioactivity, as well as radioactive fallout.

In general it is necessary to separate the phenomena connected with altitude detonations from those in the atmospheric layer near the earth because the individual annihilation factors here not only reveal major quantitative differences but also introduce a series of qualitatively new features. For methodological reasons we will however tackle this problem complex later. For detonations in the atmosphere's layer near the earth we can say the following quite generally:

The higher the altitude of a nuclear weapon detonation, the greater will be the ranges of light radiation and the blast waves.

The lower the altitude of a nuclear weapon detonation, the more effective will be the blast wave and the instant nuclear radiation in the area around ground zero.

The closer a nuclear weapon detonation is to the surface of the ground or the water, the greater will be the after effects.

Table 2.7. Effects of Nuclear Weapon Detonation as a Function of Detonation Altitude

	1 Art der Detonation			
	2 hohe Luftdetonation	3 niedrige Luftdetonation	4 Erddetonation	5 unterirdische Detonation
6 Druckwelle	++	++	+	+
7 Lichtstrahlung	++	++	+	−
8 Sofortkernstrahlung	+	++	++	−
9 Trichterbildung	−	−	+	++
10 neutroneninduzierte Aktivität	−	+	++	++
11 Restkernstrahlung (radioaktiver Niederschlag)	−	−	++	++

Key: 1--Type of detonation; 2--High air detonation; 3--Low air detonation; 4--Ground detonation; 5--Underground detonation; 6--Blast wave; 7--Light radiation; 8--Instant nuclear radiation; 9--Crater formation; 10--Neutron-induced radioactivity; 11--Residual nuclear radiation (radioactive fallout). Here is the meaning of the symbols in the table: - practically no effect; + effect; ++ severe effect. The data here for the annihilation factors refer to the range, whereas for the after effects they refer to the size or circumference.

2.2.2.1. Air Bursts

In case of air bursts, nuclear weapons are exploded at such a minimum altitude above the earth's surface in the atmospheric layer near the earth that the developing fireball will not touch the earth or the water.[21]

By way of restriction however it must be observed in this connection that such bursts--in which there are almost no effects on objects on the ground--must be included among altitude bursts regardless of the absolute detonation altitudes.[22] For the better description of the peculiarities of the annihilating effects, we distinguish between low and high air bursts.

Low air bursts are those which take place within an altitude interval of:

$$40 \cdot q^{1/3} < H_D < 100 \cdot q^{1/3} \quad \text{m} \qquad (2.32)$$

As the mean value for low air bursts we can accept the following relationship as a function of the detonation intensity:

$$H_D \approx 70 \cdot q^{1/3} \quad \text{m} \qquad (2.33)$$

High air bursts are those which take place within an altitude interval of:

$$100 \cdot q^{1/3} < H_D < 150 \cdot q^{1/3} \quad \text{m} \qquad (2.34)$$

As the mean value for high air bursts we can accept the following relationship as a function of the detonation intensity:

$$H_D \approx 120 \cdot q^{1/3} \quad m \qquad (2.35)$$

As a function of the strength and resistance of the target to be hit, air blasts can also be triggered at an altitude of $H_D > 150 \cdot q^{1/3}$ m.

The effects of the individual annihilation factors can in an elementary way be sketched as follows.

In the case of high air bursts, the blast wave (with relatively smaller overpressure values) and the light radiation have great ranges. The destruction radii for hardened installations are smaller, those of industrial buildings and residential buildings are somewhat larger than in the case of low air bursts and ground bursts. Light radiation and instant nuclear radiation have a less powerful effect on troops quartered without protection than in the case of low air bursts. The neutron-induced radioactivity of the detonation area is minor and does not represent a threat to subsequent actions by military units.

Because the dust column swept up from the ground is not merged with the detonation cloud, there is no locally significant radioactive fallout (apart from extreme weather conditions) and as a rule there will be no pronounced radioactive fallout region (radioactive trace) in the direction in which the detonation cloud moves off. There will be no detonation crater.

From what we have said so far we can conclude by way of summary that high air bursts are based on the utilization of the directly destructive or annihilating effects of the blast wave and light radiation, avoiding undesirable after effects upon subsequent combat operations.

In the case of low air bursts, the blast wave reveals high overpressure values in the area around ground zero. Light radiation and instant nuclear radiation have a severe effect on troops immediately in the detonation area, although the range is smaller. In a radius of several hundred meters around ground zero, the neutron flow, following detonations in the kiloton range, causes significant radioactive contamination of the terrain. The lower the detonation altitude, the greater is the probability that the smoke and dust column will partly be merged with the radioactive detonation cloud. This can introduce the danger of a certain local radioactive fallout which can have an effect on subsequent military operations although this effect as a rule is not decisive.

This applies above all if we fall significantly below the so-called fallout-safe detonation altitude.[23] There will be no detonation crater.

By way of summary we can observe that low air bursts in the semistrategic-tactical context in many cases can cause the greatest effects.

We will not go any further into the typical external characteristics of an air burst because the development of the fireball, the detonation crater, and the detonation cloud was already thoroughly covered in the preceding section as a function of the detonation altitude.

The diagram in figures 2.11a to 2.11e, showing the development of an air burst, can be understood also without any written explanation.[25]

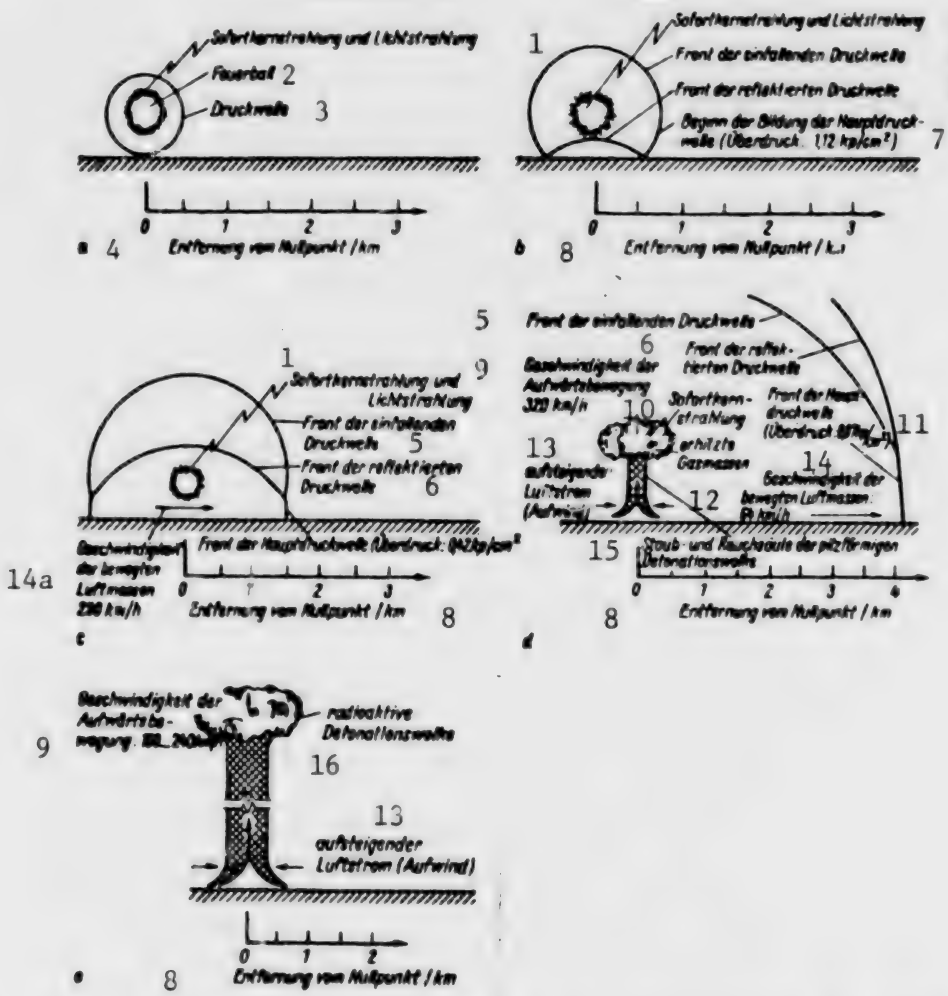


Figure 2.11. Schematic illustration of the development of a 20-kt air burst. a--0.5 sec after detonation (here and in the following related to the point in time of nuclear weapon ignition; b--1.25 sec after detonation; c--3 sec after detonation; d--10 sec after detonation; e--30 sec after detonation. Key: 1--Instant nuclear radiation and light radiation; 2--Fireball; 3--Blast wave; 4--Distance from ground zero, km; 5--Front of incident blast wave; 6--Front of reflected blast wave; 7--Start of formation of main blast wave (overpressure: 1.12 kp/cm^2); 8--Distance from ground zero, km; 9--Speed of upward movement, 320 km/hr; 10--Instant nuclear radiation; 11--Front of main blast wave (overpressure: [illegible]); 12--Heated gas masses; 13--Rising air current (anabatic wind); 14--Speed of air masses in motion: 64 km/hr; 14a--Speed of air masses in motion: 230 km;hr; 15--Dust and smoke column of mushroom-like detonation cloud; 16--Radioactive detonation cloud.

2.2.2.2. Ground Bursts

In case of ground bursts, the nuclear weapon is detonated on the earth's surface or so close above it that the developing fireball will touch the surface.

On the basis of this kind of definition, all detonations--starting from the earth's surface up to a detonation altitude of $H_D < 35 \cdot q^{1/3}$ m, are construed to be ground bursts.

In looking at the problem complex resulting from that one must however observe that--depending on the specific detonation conditions in the altitude range defined--there can be considerable differences in the annihilation effects. This applies above all to the quantity of individual annihilation factors.

This is why it is customary to label detonations--which are triggered immediately on (along) the earth's surface--with the separate term "contact detonation."

In keeping with current terminology, nuclear detonations in the earth are called underground detonations. This type of detonation will be covered in greater detail in the following section. At this point we might merely say that detonations at very shallow depths (depending on the detonation intensity) in terms of their essential characteristics hardly differ from contact detonations.

This is why we might observe by way of summary that, in the case of nuclear weapon detonations, which take place in an altitude interval of:

$$-5 \cdot q^{1/3} < H_D < 35 \cdot q^{1/3} \quad \mathrm{m} \qquad (2.36)$$

we will above all note a series of common qualitative characteristics regarding the radioactive contamination of the ground but also concerning other annihilation factors.

The effects of the individual annihilation factors can in the case of a ground burst be described roughly as follows: in the area around ground zero, the blast wave, spreading mostly in a horizontal direction, reveals extraordinarily high overpressure values. This is why also deeper and hardened installations will be destroyed in this area. Light radiation and instant nuclear radiation have an extraordinarily severe effect on the troops, unless screening objects are present. But the annihilation radii of the blast wave, light radiation, and instant nuclear radiation as a whole are smaller than in the case of air bursts. The characteristic peculiarity of a ground blast however consists in the severe radioactive contamination of the terrain. The size and dimension of the radioactive contamination of the immediate detonation area and of the terrain in the direction in which the radioactive detonation cloud moves off are in particular dependent on the detonation intensity and the detonation altitude and are furthermore essentially influenced by the weather conditions. The heaviest radioactive contamination, regarding the dimensions

of the radioactively contaminated area, revealing high dose exposures, is found after contact detonation. In this way, residual nuclear radiation becomes a main annihilation factor after ground bursts.

As a result of a ground burst, we can get a detonation crater which will be extraordinarily heavily radioactive both because of neutron-induced radioactivity and because of fission products. As a function of the detonation altitude, the crater, in case of detonations in the upper boundary spread, will be very flat and in case of contact detonations it will then assume the dimensions given in Section 2.1.3. Maximum crater formation will be attained only after underground detonations.

By way of summary we can observe that ground bursts are used primarily to hit groups in hardened shelters and to strike at massive installations whose annihilation or destruction require high overpressure values. The characteristic thing here is the appearance of large-surface, heavily radioactive areas which considerably contribute to the increase of the overall effects deriving from the detonation but which can also restrict further actions by the troops in terms of time and space as a function of the specific combat situation. Beyond that, crater formation can become a significant obstacle.

We will not present here a chronological description of the development of a ground burst. The peculiarities resulting here in contrast to an air burst will be taken into consideration in our coverage of the individual annihilation factors.

Concerning the differentiation of air bursts and ground bursts through visual operation, it must be pointed out once again that the color of the detonation mushroom is not a clear characteristic. It must be observed that, in case of air bursts, during the first development phase of the detonation cloud, there is a definite differentiation between the cloud and the stem. The features connected with the shape of the fireball cannot be observed visually without special aids.

2.2.2.3. Underground Blasts

In case of underground detonations, the nuclear weapon is exploded in the ground. The phenomena of detonation and their effects depend heavily on the detonation depth. This is why one must basically differentiate between underground detonations with external effects and underground detonations with internal effects.

Underground detonations with external effects are detonations at relatively shallow depth where the fireball breaks through the earth's surface and an open detonation crater is formed.

Underground detonations with internal effects are also called tunnel [gallery] detonations. They take place at the kind of depth at which the detonation energy remains completely in the earth so that there will be no visible changes on the earth's surface.

The effects of an underground detonation are extraordinarily strongly connected with the phenomena of crater or cavern formation because they to a certain extent reflect the distribution of detonation energy. The problem complex related to that was already discussed in our treatment of the detonation crater in Section 2.1.3. On the basis of the considerations presented there, we can arrange the effects of underground detonations schematically roughly as follows:

Underground detonations immediately below the earth's surface;

Underground detonations up to the kind of depth which will lead to maximum crater formation;

Underground detonations to a depth which will still lead to significant destruction on the earth's surface;

Underground detonations leading to complete internal effect.

The ranges mentioned here can be estimated on the basis of the general formula for the detonation depth:

$$-H_D = k \cdot q^{1/3} \quad \text{m} \qquad (2.37)$$

whereby the values for k in the sequence given take on the magnitude 5, 50, 95, or 120. These are only very rough guidance figures here. In this subdivision of underground detonations it is likewise impossible logically to arrange all developing phenomena. But some useful practical conclusions can be derived in tactical respects.

Underground detonations immediately below the earth's surface resemble ground bursts in terms of their characteristics. Their annihilation factors can be described with the help of the features taken up in conjunction with the description of ground bursts.

In case of an underground detonation up to the kind of depth which lead to maximum crater formation, the main annihilation factor is the compression wave spreading in the ground. In the following, detonations at such a depth are referred to as underground detonations, for short.

The characteristic aspect of an underground detonation thus consists in the fact that the blast wave is propagated almost exclusively in the ground as a function of the detonation depth and that it leads to seismic shocks here similar to an earthquake. Light radiation is for the most part consumed for the melting and evaporation of the ground and thus does not take effect in the area around ground zero, just like instant nuclear radiation.

The detonation crater assumes considerable dimensions and is extraordinarily heavily radioactive. We get a very high level of local terrain contamination in the direction of detonation cloud evacuation whereby the dimensions of the radioactively contaminated zones with a certain dose exposure vary greatly

with the detonation depth; they can be both smaller and larger than in the case of ground bursts.

By way of summary we can observe that underground detonations first of all are used for the destruction of hardened underground installations and for the creation of obstacles due to crater formation and radioactive fallout.

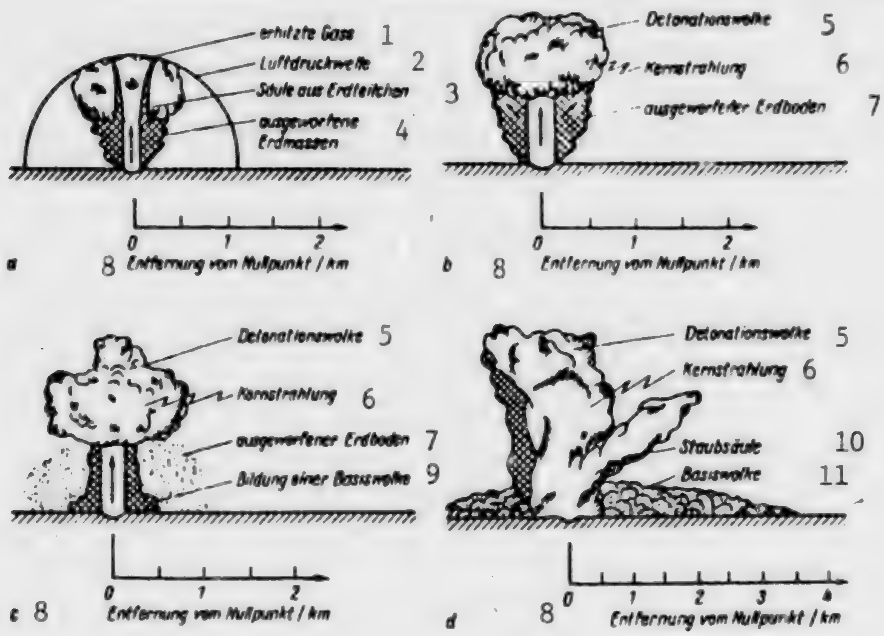


Figure 2.14. Diagram illustrating the development of an underground detonation with detonation intensity of 100 kt.[28] a--2 sec after detonation; b--9 sec after detonation; c--45 sec after detonation; d--4.5 min after detonation. Key: 1--Heated gases; 2--Air blast wave; 3--Column of earth particles; 4--Ejected earth masses; 5--Detonation cloud; 6--Nuclear radiation; 7--Ejected earth [ground]; 8--Distance from ground zero, km; 9--Formation of base cloud; 10--Dust column; 11--Base cloud.

(a) In case of the detonation of a nuclear weapon at shallow depth, the fireball will break through the earth's surface within fractions of a second. Mighty masses of air are swept upward by the hot, highly-compressed gases in the form of a high column(1 million t).

A heavily radioactive cloud is formed due to cooling and condensation.

The air blast wave spreads horizontally. A compression wave arises on the ground.

(b) The detonation cloud continues to rise. The nuclear radiation, emitted by the radioactive detonation products in the cloud, has a strong effect on the earth's surface. Larger earth particles fall back to the ground.

(c) As a result of the dust and earth masses which fall back down, a cloud is formed around the stem of the detonation cloud around the earth's surface;

it consists of fine dust particles and its development progresses radially from ground zero toward the outside. Here we speak of the so-called base cloud. (d) The base cloud rises and its surface increases and it merges partly with the detonation cloud. Both of them spread mostly in the direction of the wind and cause heavy local radioactive fallout.

2.2.2.4. Water and Underwater Detonations

Water detonations are detonations on the water's surface or at an altitude at which the fireball will touch the water's surface. A nuclear weapon detonation in the water is an underwater detonation. In describing both of the above-mentioned detonation types, one must consider viewpoints similar to those that were mentioned earlier in connection with the description of underground detonations.

Here again we can say that the phenomena of the detonation and the action mechanisms of the developing annihilation factors are by no means uniform but vary greatly as a function of the detonation depth or altitude. On top of that we have the fact that the depth of the water also exerts great influence. These and other factors make generalization possible only with certain reservations.

Water detonations are very similar to ground detonations in terms of their essential characteristics. But they also reveal some peculiarities. As a function of the detonation altitude, a part of the energy takes effect in the water as blast wave. As a result of this, the blast waves spreading in the water and in the air supplement each other in terms of their effect on ships and shore installations. Besides, there are additionally high water waves which spread concentrically from the detonation center. Because of that we must expect shore areas to be flooded where the coastline is flat.

Because of the intimate mixing of the ejected water masses with the radioactive detonation products, we get a powerful radioactive contamination of the detonation area. As in the case of ground bursts, there is an extensive radioactive fallout area in the direction in which the detonation cloud moves off. Radioactive fallout here appears mostly as rain. In case of detonations over flat water bodies with a depth of no more than 15 m, the degree of radioactive contamination roughly corresponds to that of ground bursts. At greater water depths, the radioactive contamination values approach those found after air blasts.

By way of summary we can observe that water detonations are employed above all to engage ships, ports, shore installations, barriers, and other objects near the coast or the shore. Water detonations furthermore lead to severe, large-area terrain contamination which, in case of corresponding weather conditions, after detonations near the coast, can also greatly influence ground forces operations.

As the detonation altitude decreases or as the detonation depth increases, water detonations gradually become underwater detonations. The blast wave is propagated almost exclusively in the water. Light radiation and instant

nuclear radiation are heavily absorbed and do not have any significant range. Huge masses of water are ejected as a result of detonation; at 100 kt, they would amount to something like 1 million t; in case of detonations near the ground, earth masses would also be ejected. The direct radioactive contamination of the more immediate and further detonation area is greater than in the case of water detonation. The radioactive fallout area however is considerably smaller. Underwater detonations have an effect primarily because of the blast wave spreading in the water which hits the underwater part of ships and underwater installations. Besides, the more than 10-m high water waves cause additional destruction and can also lead to flooding.

By way of summary we can observe that underwater detonations are employed for the purpose of engaging ships and to destroy water-engineering installations and heavily fortified coastal objects.

Figures 2.16a-e illsutrate the development of an underwater detonation at shallow depth. Because of the fact that the external characteristics here likewise differ considerably from those in Section 2.1, the description here is somewhat more broad although heavily simplified.[30]

(a) The detonation takes place at shallow depth. Due to the action of the fireball, a bubble, consisting of highly-heated and heavily-compressed gases, develops in the water; it breaks through the water's surface and in the process ejects a hollow column of water and foam which reaches an altitude of about 1,500 m after 2 sec, following a 100-kt detonation.

The gaseous detonation product lies inside the hollow cylinder and is condensed after cooling along its topside.

The blastwave originating in the water spreads at fast speed and 2 sec after detonation is about 3.5 km away from ground zero.

The front of the relatively weak air blast wave at the same moment is about 1,300 m from ground zero. In the area covered by the blast wave, a condensation cloud is formed for a few seconds.

(b) At this point in time, the water cylinder has developed further. A cloud consisting of detonation products and water vapor rises above it. It is highly radioactive and emits nuclear radiation. The water column begins to fall back slowly. As a result of this, a base cloud is formed at its foot, consisting of the very finest water drops or mist. It is highly radioactive.

Surface waves spread from the detonation center; 12 sec after the detonation, the first wave has a height of about 50 m (wave mount to wave trough) and is about 550 m from ground zero.

(c) The base cloud develops further because of the collapse of the water and foam column. At the point in time considered, its height is about 300 m, its forward distance from ground zero is 800 m. Large masses of water begin to fall out of the cloud. The water column still has a diameter of 600 m. The first surface wave is 600 m away from ground zero.

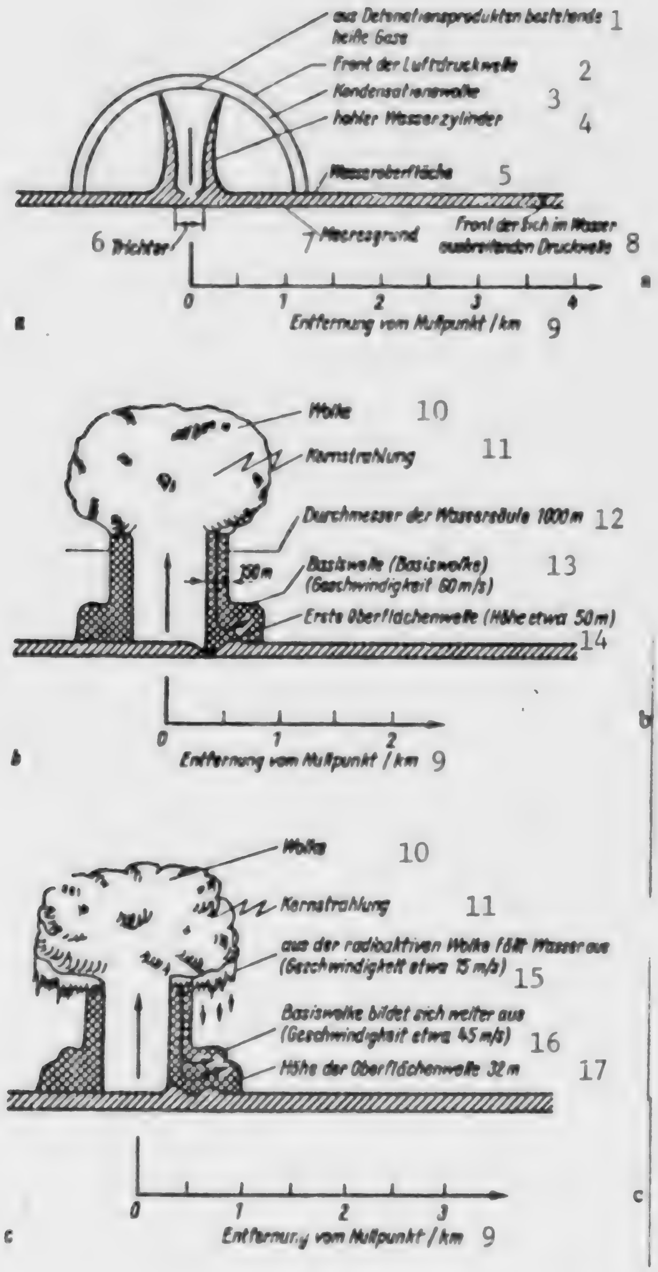
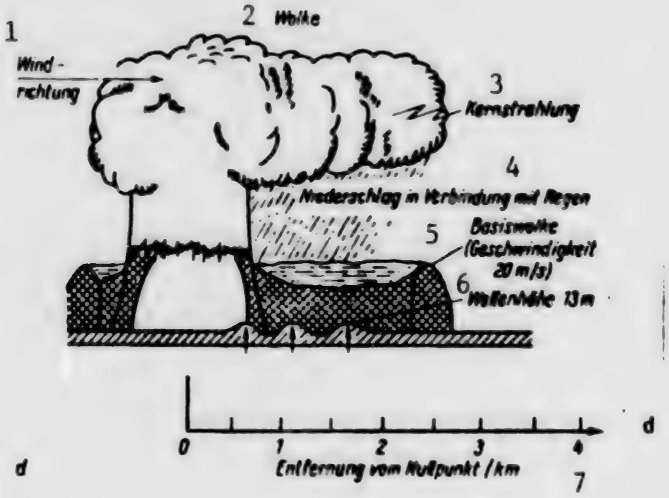
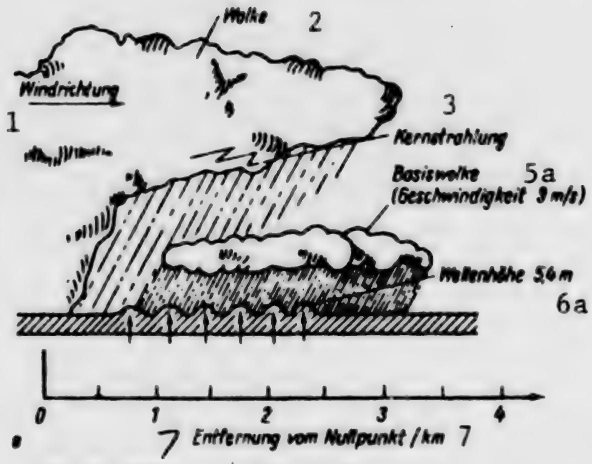


Figure 2.16. Diagram illustrating the development of an underwater detonation with a detonation intensity of 100 kt. a--2 sec after detonation; b--12 sec after detonation; c--20 sec after detonation. Key: 1--Hot gases consisting of detonation products; 2--Air blast wave front; 3--Condensation cloud; 4--Hollow water cylinder; 5--Water surface; 6--Crater; 7--Ocean bottom; 8--Front of blast wave spreading in water; 9--Distance from ground zero, km; 10--Cloud; 11--Nuclear radiation; 12--Diameter of water column, 1,000 m; 13--Base wave (base cloud), speed 60 m/sec; 14--First surface wave (height about 50 m); 15--Water is precipitated from the radioactive cloud (speed about 15 m/sec); 16--Base cloud grows (speed about 45 m/sec); 17--Height of surface wave 32 m.



d



e

Key: d--1 min after detonation; e--2.5 min after detonation; 1--Wind direction; 2--Cloud; 3--Nuclear radiation; 4--Fallout combined with rainfall; 5--Base cloud, speed 20 m/sec; 5a--Base cloud, speed 3 m/sec; 6--Wave height 13 m; 6a--Wave height 5.4 m; 7--Distance from ground zero, km.

(d) At the point in time considered, the fallout, coming out of the detonation cloud in the form of rain, hits the water's surface. Between the cloud and the water's surface we now have a continuous region of water, foam, and mist. The base cloud is now about 400 m high; it has moved more than 2 km away from ground zero and is swept along at a speed of about 20 m sec^{-1}. Other surface waves have formed and have moved away from ground zero.

(e) After 2.5 min, the base cloud with its forward boundary is about 3.2 km away from ground zero (after 4 min, a length of about 4 km is reached). It has a height of 600 m and has separated from the water's surface.

The detonation cloud and the base cloud release rainfall. The mist fields formed on the water's surface due to the collapse of the water and foam column are dissolved. The rest of the actual detonation cloud is driven away by the wind and is mixed with the surrounding air layers.

2.2.2.5. High-Altitude Detonation

The term high-altitude detonation here is used in a simplified manner for all detonations taking place at an altitude that does not constitute a threat to objects on earth. The dependence of a possible subdivision here in terms of the detonation intensity emerges already from this observation.[31]

High-altitude bursts are further subdivided in keeping with their character as follows:

Troposphere detonations (10 km < $H_D \leqq$ 15 km);
Stratosphere detonations (15 km < $H_D \leqq$ 50 km);
Ionosphere detonations (50 km < $H_D \leqq$ 150 km);
Cosmic detonations (H_D > 150 km).

The numerical values given in parentheses represent the typical detonation altitude ranges.[32]

This subdivision takes into account the changes in the state of the atmosphere as the altitude increases, especially the decrease in air pressure and air density.

These parameters on the one hand do have an effect on the effect of the detonations, especially on the distribution of detonation energy over the individual energy forms in the shape of the developing annihilation factors and on the other hand they influence the propagation of range of the individual annihilation factors themselves.

This produces a change not only in qualitative characteristics of a detonation but also in its quantitative characteristics.

Troposphere and Stratosphere Detonations

Detonations in these altitude ranges essentially develop according to the characteristics of detonations in the atmosphere's layer near the earth. The developing annihilation factors are blast wave, light radiation, and instant nuclear radiation. The radioactive contamination of the terrain and thus the residual nuclear radiation on the other hand have no practical local significance. The essential peculiarities emerge increasingly clearly as the detonation altitude grows. Up to an altitude of about 25 km one may assume that the part of the detonation area found in the blast wave roughly corresponds to the one encountered in detonations in the atmosphere's layer near the earth. In case of altitudes of more than 25 km on the other hand the share for the blast wave decreases considerably. Here we must furthermore keep in mind that, because of the decline in the air density along with the altitude, the overpressure values in the blast wave front encountered at the particular distances are also reduced in a similar manner.

The detonation energy, released in the form of light radiation, increases percentage wise as the detonation altitude grows. In addition we have the

fact that--because of the low air density and the resultant greater dimensions of the fireball--the effect of light radiation is greater than in the case of detonations near the earth.

Regarding the effect of instant nuclear radiation, the reduction in the air density and thus the decline of the linear attenuation is noticed over a considerably greater range. The same cause explains the phenomenon to the effect that, as the detonation altitude goes up, the share of the neutron dose out of the total dose grows over the same distance.[33]

In general we can observe that troposphere and stratosphere detonations are employed to engage aircraft and missiles.

In case of detonations of up to an altitude of 25 km, the blast wave is the main annihilation factor. In detonations at greater altitudes, the light radiation in particular has an effect due to the severe heating of the objects to be engaged, plus subsequent destruction.

Instant nuclear radiation and light radiation can also have an effect on aircraft crews.[34]

Ionosphere Detonations

In ionosphere detonations, the part of the detonation energy appearing as blast wave is further reduced; at the same time, the percentage share of light radiation also drops rapidly.

By way of annihilation factors we have extraordinarily intensive x-ray radiation, neutron flow, as well as rapidly spreading detonation products. The x-ray radiation, which is propagated over great distances, upon hitting an obstacle, causes a powerful heating of a thin surface layer as a result of which there is a detonation-like evaporation, followed by corresponding pressure impulses. Additional pressure stresses arise due to the gaseous detonation products.

The neutron flow in particular has an effect on the nuclear charge as well as the electronic part of warheads. Another essential feature of ionosphere detonations consists in the generation of a heavily ionized area which under certain circumstances can have a severely disturbing effect on short-wave radio operations for periods of up to hours.

In conclusion we can say that ionosphere detonations are employed above all to engage warheads in ballistic missiles. The main annihilation factor here is x-ray radiation. The immediate effect of an ionosphere detonation is limited to a radius of several hundred meters up to several kilometers also increase of higher detonation intensity.

Cosmic Detonations

Nuclear weapon detonations at these altitudes take place practically under the conditions of a vacuum. Here the detonation energy is mostly released

in the form of radiation energy. The detonation products move over great distances (100 km and more) at fast speeds. In this type of detonation likewise there is a strong, longer-lasting ionization of the atmosphere. But this problem complex will be covered in greater detail later on.

Review Questions

2.15. What are the annihilation factors connected with nuclear weapon detonations? Describe them!

2.16. Explain why the type of detonation is a function of the detonation altitude and derive the resultant conclusions.

2.17. What detonation types or subtypes are distinguished in military terminology?

2.18. Describe the most important detonation types.

2.19. What essential differences are there in the case of air, ground, and underground detonations regarding the effect and range of the individual annihilation factors?

2.20. Why is a clear differentiation of air and ground blasts of fundamental significance in preparing a situation estimate after enemy nuclear weapons strikes?

2.21. What basic significance is attached to underground detonations (nuclear mines) in ground forces combat operations?

2.3. Means and Methods to Determine the Initial Data of Nuclear Weapon Detonations

The totality of means and methods to determine the initial data of nuclear weapon detonations is referred to as nuclear weapon detonometry. Nuclear weapon detonometry is an important component of unit nuclear defense. Its uninterrupted organization and management is an essential prerequisite for a rapid evaluation of the situation, arising after enemy nuclear weapons strikes, by commanders and staffs as well as for the direct restoration of combat readiness and the elimination of the consequences for the sake of the accomplishment of the combat missions assigned.

Nuclear weapon detonometry must quickly and accurately supply the following initial data on enemy nuclear weapons strikes:

Detonation time;

Detonation site (coordination of ground zero or detonation point);

Detonation type and

Detonation intensity.

The extent to which and the accuracy with which these initial data can be supplied by the various observation agencies will among other things depend on the available equipment and aides as well as the particular distance from the detonation site and the weather and terrain conditions.

Regarding nuclear weapon detonometry, one must basically distinguish between field processes (means and methods) and those which can be applied under territorial, stationary conditions.

Thus, the initial data can be determined on the basis of the external features of a detonation (detonation crater, fireball, detonation cloud, effect of individual annihilation factors) by estimating or measuring (the running time of the blast or sound wave, the climbing speed, climbing height, climbing time, and dimensions of the fireball or the detonation cloud, etc.) with relatively simple aids or with the help of special detonometric instruments (registration and measurement of light impulse curve, seismic measurements, etc.) as well as other technical instruments, such as radar stations.

In terms of equipment, the initial data on nuclear weapon detonations can be based on radio, radio-engineering, optical, and seismic processes, whereby they as a rule are employed in a combined fashion.

These processes are described theoretically in great detail in the book by Longhans, entitled "Kernwaffenradiometrie und Kernwaffendetonometrie" [Nuclear Weapon Radiometry and Nuclear Weapon Detonometry], published by the Military Publishing House of the German Democratic Republic in 1970;further coverage of individual instruments is not possible in this particular context; this is why we will in the following take a closer look only at some simple, universal processes of nuclear weapon detonometry under field conditions.

The determination of the detonation time does not require any special instruments to be issued to the particular observers because the data as to the point in time involved in a nuclear weapon detonation can normally be given in a completely adequate fashion with an accuracy of several minutes.

The detonation time is related to local time or also to a certain X-time. For practical calculations in the context of analysis by staffs, detonations --which take place within a span of 15-30 min--can be related to a common average time. This kind of approach is readily permissible because, for example, calculations on the nuclear radiation situation in smaller time intervals hardly make any sense at all.

Assuming that the observer's station is known, the determination of the detonation site (ground zero coordinates) requires the determination of the direction and distance with respect to the detonation center.

For this purpose, a profile must be made of the detonation cloud because the fireball, due to its brightness and relatively short illumination time, is beyond the reach of direct operation at the distances that are of interest here. The azimuth to the detonation cloud's center can be determined with

a prismatic compass or other aids according to march movement azimuth numbers, degrees, or mil.

This also gives us the rough location of the detonation's ground zero if we have at least two OP's at the point of intersection of both azimuths on the map.

In the other case, the distance of the detonation site can be determined with the help of the running time of the blast wave (sound wave); that is to say, the time span between the flash of the fireball and the audibility of the detonation report. The running time itself can be counted or, better still, it can be measured with a stopwatch. Here of course there is a certain time delay which influences the measurement result negatively.

The following approximation formulas apply to the determination of the distance:

$$r = 0{,}4 \cdot t \text{ km für } t \leq 25 \text{ s}$$
$$r = 0{,}3 \cdot t \text{ km für } t > 25 \text{ s} \qquad (2.38)$$

The type of detonation can be judged directly at the moment of or after the detonation only according to the external appearance. The phenomena which can be used for this (fireball, detonation cloud, detonation crater) were described in elementary fashion already in Section 2.1 and were then further interpreted in section 2.2 during the description of the types of detonations. This is why only the most important criteria are compiled in Table 2.8 in the form of an overview. A direct determination of the detonation altitude is impossible visually or with simple aids.

If the character of a detonation cannot be determined or if it cannot be determined clearly, then--in making the analytical evaluation--one must start with the variant which is most unfavorable for further actions by friendly troops, that is to say, we must as a rule assume a ground burst.

All possibilities of direct observation of the detonation area must then furthermore be used and conclusions must be drawn from the secondary phenomena, such as the appearance of heavy radioactive fallout. Among the theoretically highly manifold possibilities for the determination of the detonation intensity, only a few can be used without major technical effort and they can be used only with restrictions.

Here we have the following:

Estimating or measuring the duration of illumination provided by the fireball,
Determining the maximum ascent height of the detonation cloud,

Determining the horizontal extent of the detonation cloud at the moment of its stabilization and

Recording the characteristic annihilation radii in the field.

Table 2.8. Overview of the Most Important External Phenomena Usable in Determining the Individual Detonation Types

Detonation Type	Fireball	Detonation Cloud	Detonation crater	Other Phenomena
High-altitude detonations	Visible far away at relatively high altitude above horizon; Spherical; Uniform shape	Consists only of condensation cloud	Not present	Wide time difference between flash of light and audibility of detonation report
High-altitude air bursts	Glaring flash of lightning; Spherical; Easily visible	Slim stem of dust column; no or only little merger between stem and condensation cloud; "Bright coloration"	Not present	Detonation area relatively well observable
Low-altitude air bursts	Glaring flash of lightning; Flattened off along its underside immediately during the first few seconds of its ascent	Slim stem of dust column; Merger between stem and condensation cloud takes place only during ascent	Cracks and crevices possible in area of ground zero	Formation of weak "base cloud"; Detonation area poorly observable
Ground bursts	Glaring flash of lightning; Flattened off more or less hemispherically along the underside; Screening effect due to expelled dust masses	Continuing detonation cloud from the very beginning; Short stem with wide diameter	Present; Flat	Formation of "base cloud"; Detonation area not observable; Spread of weak seismic and ground pressure waves

Table 2.8 [Continued from preceding page]

Detonation Type	Fireball	Detonation Cloud	Detonation crater	Other Phenomena
Underground detonations	Invisible or only slightly visible	Typical shape of "ejecta cloud"	Present; Deep; Huge crater pile-up	Effect of light radiation missing or only weak; Severe earth shock with following tremors; Fallout from detonation cloud near ground zero can be observed well

In many cases it will only be possible to determine the detonation intensity in terms of orders of magnitude. Further conclusions can be drawn also from reports from the directly or indirectly affected units, from the severance of contact with certain units, installations, etc. Between the duration of illumination from the fireball and the detonation intensity there is the following connection which was already formulated in section 2.1.1:

$$t_L \sim q^{1/3} \quad \text{s} \qquad (2.39)$$

Direct observation of the fireball causes severe eye damage. This is why stray light must be used for estimating or measuring. Because the values for t_L differ only little in detonations on the same order of magnitude, we must expect major errors, above all in the detonation intensities below 100 kt (see data in Table 2.2).

In determining the detonation intensity from the maximum ascent height of the detonation cloud (Table 2.3), we must consider the influencing magnitudes already explained in Section 2.1.2. This is why any excessive accuracy in the interpretation of observation results is misplaced here. For this reason, we can as a rule neglect elevation differences in the observer's sight with respect to the detonation area.

Under these conditions, the altitude of the upper cloud limit $\bar{H}$ can be calculated from the observer's distance from ground zero and the elevation angle according to the following relationship:

$$\bar{H} = r \cdot \tan \alpha \quad \text{km} \qquad (2.40)$$

The elevation angle α can be determined with the help of the HWM-1 [elevation angle measurement device]. The pertinent tangent values are contained in a table on the protractor.

The upper cloud limit is sighted across the sight notch [rear sight] and front sight while at the same time squeezing the trigger. By releasing the trigger, we stop the mobile pendulum (plumb line) and the elevation angle can then be read off.

Conclusions as to the detonation intensity can also be drawn from the ascent speed of the detonation cloud. For this purpose we must measure the upper cloud limit according to the described method at various times after the detonation. Special tables or graphs are needed to analyze the measurement results.

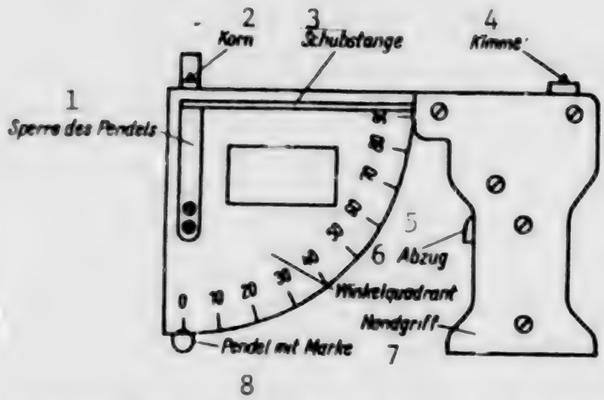


Figure 2.17. The HWM-1 elevation protractor: Key: 1--Pendulum lock; 2--Front sight; 3--Pushrod; 4--Rear sight; 5--Trigger; 6--Angle quadrant; 7--Handle; 8--Pendulum with marker.

Another method of determining the detonation intensity consists in the measurement or estimation of the horizontal dimensions of the detonation cloud. The results obtained here are rather little accurate because of the heavy influence deriving from the specific temperature stratification of the atmosphere at the moment of detonation. The mil subdivision of the scissors telescope can be used as a simple aid.

The horizontal diameter D_W of the detonation cloud can be calculated as follows if we know the distance r:

$$D_W = \frac{r \cdot \text{mil}}{1,000} \text{ km} \tag{2.41}$$

This involves the use of the so-called 1/1,000 formula. The mil figure is based on the fact that the full circle is subdivided into 6,000 mil instead of 360°. In this kind of subdivision, 1 mil (0-01) corresponds to an object 1 m wide or high which is 1,000 m away from the observer.[35]

Review Questions

2.22. Explain the purpose of nuclear weapon detonometry.

2.23. Why must analytical evaluation and rapid observation of the detonation areas form a unit?

2.24. Why must the information contained in Table 2.8 be considered only as rough guidance figures?

2.25. What simple methods of determining the initial data of enemy nuclear weapons strikes can be used under which conditions?

2.26. Why does nuclear weapon detonometry under field conditions in many cases only permit approximate statements as to the initial data of a nuclear weapon detonation?

2.4. Footnotes for Chapter 2

1. Further descriptions are oriented essentially toward the description of air, ground, and underground bursts. Some of the peculiarities connected with underwater and high-altitude detonations will be covered in greater detail during the discussion of the detonation types in Section 2.2.

This is necessary because the specified scope of the textbook does not make it possible to describe the course of a large number of nuclear weapon detonations chronologically. Basic detonation descriptions can be found among others in Langhans, K., "Kernwaffen und ihre Wirkungen," Publishing House of the Interior Ministry, Berlin, 1960. For further study, reference is made to the literature sources given.

2. The derivation of the energy concentrations, maximum temperatures, and maximum pressures, appearing as a result of nuclear weapon detonations, was already presented in Section 1.3.4. At this point we might only observe by way of supplementation that, in case of nuclear weapon detonations in the Megaton range, the corresponding values can be higher by one order of magnitude in each case.

3. See also the description in Section 1.3.4, especially Formula 1.19.

4. Schrader, R., "The Physics of Nuclear Explosions and the Effect of Nuclear Weapons," NATURWISSENSCHAFTLICHE RUNDSCHAU [Natural Science Review], 1958, 7, p 268.

5. Lapple, C. E., "Fallout Control," SRI Project No SU 2479, USAEC, San Francisco, 1958; quoted from Fuchs, S., "Mathematical Methods for the Approximate Determination of Radioactive Terrain Contamination and the Resultant Conclusions for the Commander," dissertation, "Friedrich Engels" Military Academy, 1964, p 41.

6. Fuchs, S., "Mathematical Methods...," loc. cit., p 38.

7. Wilckens, F., "Radioactivity in the Air due to Nuclear Explosions," SOLDAT UND TECHNIK [Soldier and Technology], 1959, 6, p 292.

8. The illustration was taken from "FAA Course of Radiological Monitors."

9. Fuchs, S., "Mathematical Methods...," loc. cit., pp 35-40.

10. See also Flohn, H., and R. Penndorf, "The Stratification of the Atmosphere, (1)." BULL OF THE AM MET SOC, 31, 1950, p 71.

11. Nifontov, B. I., and others, "Underground Nuclear Detonations," Atomizdat, 1965, Russian. (An attempt is made in this work to provide a comprehensive illustration of the general laws on the basis of an analysis of almost 100 publications on this problem complex.)

12. Nordyke, M D., "New Scientist," 15, 1962, p 294.

13. It is understandable that the term "sandy and clayey soils" only incompletely reproduces the real conditions in the particular detonation area. Other publications give the crater diameter at 40 m and the crater depth at 9 m when q = 1 kt. By using the similarity laws, these deviations naturally are propagated and lead to a corresponding difference when we compare the values given by the various authors in their tables.

14. Further details on this question can be found among others in Nifontov, "Underground Nuclear Detonations," loc. cit., p 26 f.

15. To achieve agreement with already available documents, the values in Table 2.4 however were calculated with an exponential coefficient having the value of $x = 1/3$. The differences appearing with respect to $x = 1/3.4$ are minor and are of no significance in military practice. Besides, the calculations in the first case are also considerably simpler. When $q = 5$ Mt, we get, for example, when we use $x = 1/3$ instead of $x = 1/3.4$ not 600 m but 560 m for d_s and we get 96 m, not 100 m, for h_s.

16. The picture was taken over unaltered from Nifontov, "Underground Nuclear Detonations," loc. cit., p 29.

17. Violet, Ch. E., J. GEOPHY. RES., 66, 10, 3461, 1961, suggests the exponent of 1/3.6 for the calculation of the change in the crater parameters with the depth of the detonation and gives the average error with known ground structure here at <5 percent.

18. The picture was taken over unaltered from Nifontov, "Underground Nuclear Detonations," loc. cit., p 30.

19. Ibid., pp 32 ff.

20. The optimum detonation altitude is generally calculated by primarily considering the blast wave effects (see Chapter 3) according to the following relation:

$$H_D = k \cdot q^{1/3}$$

k in this connection is the so-called strength [hardness] factor. It was expressed in meters and, for example, is 240 for cities. An 1-kt nuclear weapon thus would have to be exploded at an altitude of 240 m to cause maximum possible destruction of houses.

21. See also the statements in Section 2.1.1. on the influence of the detonation altitude upon the shape of the fireball.

22. Langhans, K., "Definitions of Nuclear Weapon Detonation Types," MILITAER-TECHNIK, 1971, 8, p 349.

23. A detonation altitude which is fallout-proof is considered to be the kind of altitude at which no significant radioactive fallout can be expected at the particular detonation intensity with a probability of 99 percent. This altitude can be determined with adequate accuracy from the empirical relationship:

$$H_{ss} \approx 100 \cdot q^{1/3} \text{ m.}$$

24. The picture was taken from "The Effects of Nuclear Weapons," loc. cit., p 38.

25. Photos 2.11a-e were taken in a processed form from "The Effects of Nuclear Weapons," Washington, 1962, Russian edition of the above-mentioned work available from the Publishing House of the USSR Defense Ministry, Moscow, 1965, pp 90-94. Here we also have a detailed chronological detonation description.

26. The picture was taken from "The Effects of Nuclear Weapons," loc. cit., p 43.

27. The picture was taken from "The Effects of Nuclear Weapons," loc. cit., p 69.

28. The pictures were taken from "The Effects of Nuclear Weapons," loc. cit., pp 100-101.

29. The picture was taken from "The Effects of Nuclear Weapons," loc. cit., p 61.

30. Further details on this problem complex can be found in "The Effects of Nuclear Weapons," loc. cit., pp 95-99. Figure 2.16 was also taken from this source.

31. To be able to meet the requirement of "not being dangerous for objects on earth," various literature references define different criteria. For detonations in the kiloton range, the decisive factor is the blast wave. Here we have $\Delta p = 0.02$ kp cm^{-2}. In the Megaton range one must also consider the light radiation ($U \leqq 4 \ldots 6$ cal cm^{-2}).

32. In interpreting the subtypes of high-altitude detonations one must keep in mind that the altitude ranges given do not completely coincide with the generally customary subdivision of the earth spheres. But we cannot go into any greater detail on the problems deriving from that.

33. In case of a ground burst q = 50 kt we get a total dose of instant nuclear radiation amounting to 1,000 R at a distance of about 1 km. In case of a stratosphere blast at an altitude of 25 km, we measure doses on this order of magnitude at a distance 13 km from the point of detonation.

34. Looking at this problem complex one must however keep in mind that only radiation doses on the order of magnitude of 10^4 R lead to crews being knocked out instantly.

35. Concerning this problem complex, see "Handbuch Militaerisches Grundwissen," German Military Publishing House, Berlin, second revised edition, p 336 f.

3. Blast Wave from Nuclear Weapon Detonation

In general, the term blast wave means a sudden and heavy condensation of the particular medium which spreads at great speed (supersonic speed).

The propagation of the blast wave in the air, in the ground, and in water is subjected to different laws. In our chapter, the emphasis is on the treatment of the air blast wave because it is of decisive significance in estimating the annihilating effects of nuclear weapon detonations in many cases.

Some questions of blast wave propagation in the ground and in water are discussed in sections 3.3 and 3.4. In this connection it is pointed out that the processes of pressure propagation are a relatively difficult area both in physical and in mathematical terms. This why we will not go into a thorough mathematical treatment here. We only included those problems which are of basic significance in understanding the effect of the blast wave and providing protection against it.

3.1. General Characteristic of Air Blast Wave

The air blast wave from a nuclear weapon detonation arises due to the sudden and severe temperature and pressure rise in the zone of nuclear transformations.

The air blast wave represents an area of heavily compressed and heated air which spreads spherically in all directions from the detonation center. Here the pressure is in succession transmitted from the nearest air layers to the air layers that are further away from the detonation center.

The forward boundary of the air blast wave is the blast wave front. In case of undisturbed pressure propagation, this front at any moment represents the surface of a sphere.

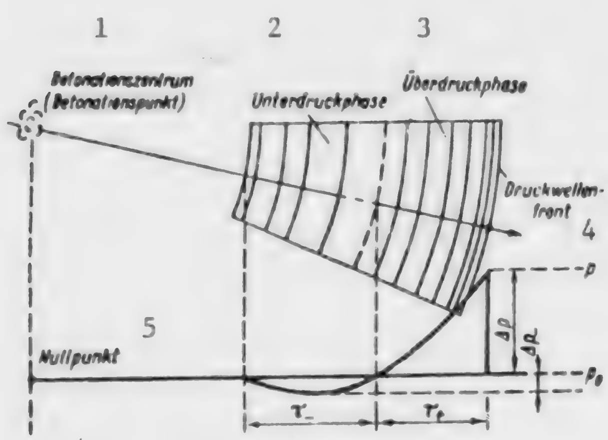


Figure 3.1. Time changes in air pressure in one place during the passage of the blast wave. Key: 1--Detonation center (detonation point); 2--Underpressure phase; 3--Overpressure phase; 4--Pressure wave front; 5--Ground zero.

As the distance from the detonation center increases, the pressure energy is distributed over an ever growing air volume. This is why the overpressure and the propagation speed of the pressure wave decrease rapidly. To describe

the air blast wave--below generally referred to briefly as blast wave--we use the following essential characteristics:

p--Absolute pressure, kp/cm^{-2};
Δp--Overpressure in blast wave, kp/cm^2;
τ_+--Duration of overpressure phase, sec;
τ_---Duration of underpressure phase, sec;
ρ--Air density, $kp/s^2/m^{-4}$;
T--Thermodynamic temperature, ° K;
D--Speed of blast wave, m/sec^{-1};
U--Speed of air in blast wave, m/sec^{-1};
C--Speed of sound in air, m/sec^{-1}.

Other necessary magnitudes will be introduced at the particular place.

If the blast wave front in its direction of propagation reaches a certain place, then the density, pressure, temperature, and speed of the air will increase there.

The air pressure will suddenly rise by the amount Δp from the normal atmospheric pressure p_0 to the value p. During time τ_+ the overpressure Δp will then gradually decrease and will reach normal atmospheric pressure.

This is why this phase of the blast wave, in which $p > p_0$ applies, is called the overpressure phase or also the compression phase. This overpressure phase is then followed by an underpressure phase or dilution phase; that is to say, during the time span τ_- the air pressure will drop below the normal atmospheric pressure.

During the process of blast wave propagation, the absolute air pressure drops constantly both along the front of the air blast wave and over its entire depth.

If however normal atmospheric air pressure has already been reached again in the detonation center, then the blast wave front at the particular distance always still reveals overpressure values. This causes the separation of the blast wave from the original detonation area and, supported by the inertia of the air masses in motion and their subsequent expansive cooling, this leads to the generation of a low-pressure area; that is to say, the formation of the underpressure phase.

The air is in motion in the blast wave. During the action time of the overpressure phase, there is a strong wind flowing in the direction of blast wave propagation, that is to say, away from the detonation center; during the underpressure phase on the other hand it moves toward the detonation center.

The annihilating effect of the blast wave can thus be traced physically to two phenomena; first of all, the heavy pressure rise as the blast wave front reaches a particular place (maximum overpressure)--where the action time of the blast wave also plays a role--and, second, the great motion energy of the air masses (dynamic overpressure) which is expressed in the form of a pressure head of impact pressure on hitting an obstacle.

Although the destructive effect of the blast wave is related mostly to the maximum overpressure in the blast wave front, one must keep in mind that, especially in some building types, the dynamic overpressure can also be very significant because it can exceed the maximum pressure in the front of the blast wave at great detonation intensities, especially near ground zero.

The dynamic pressure is a function of the air speed and the air density behind the blast wave front.

The blast wave from a nuclear weapon detonation differs from the blast wave deriving from the detonation of conventional chemical explosives above all by the fact that its action time and length are considerably greater. While, for example, in the detonation of a 2.5-dt [deciton] HE bomb, the overpressure phase at a length of about 15 m has an action time of 0.01 sec, the corresponding values for a detonation of 20 kt come to about 300 m and 1 sec.

Looking at the blast wave from a nuclear weapon detonation one must strictly distinguish between the propagation speed of pressure propagation (speed of wave front) and the speed of the air masses moved in the front of the pressure or blast wave. The difference between the speed of the blast wave and the speed of the air in motion in the blast wave is roughly equal to the speed of sound. The time which the blast wave needs to reach a certain place depends on the detonation intensity and the distance from the detonation center. Initially, the blast wave spreads with supersonic speed. As the distance increases, its speed decreases and at great distances it only reaches the speed of sound, that is to say, the blast wave becomes a sound wave. In the detonation of a nuclear weapon with an intensity of 20 kt, the initial velocity of the blast wave is more than 1,6000 m/sec^{-1}. In this way, the blast wave covers a total of about 3,000 m during the first 8 sec.

Review Questions

3.1. From what basic viewpoints must one start in a general characterization of the blast wave deriving from a nuclear weapon detonation?

3.2. Explain the change in pressure conditions in one place during the passage of the air blast wave.

3.3. Why must one absolutely keep in mind that the term "blast wave speed" describes the speed of propagation of the air blast wave front?

3.2. Air Blast Wave Propagation

3.2.1. Air Blast Wave from Air Burst

The propagation of the blast wave from an air burst in the atmospheric layer near the earth and the attendant blast wave effects are complicated. The entire action range of the blast wave can in a simplified manner be subdivided into three zones:

The near zone;

The far zone and

The zone of slightly increased pressure.

In an air blast, the blast wave initially spreads in a spherical form from the detonation center. Figure 3.2.shows the position of the blast wave fronts at times t_1 to t_4 after detonation.

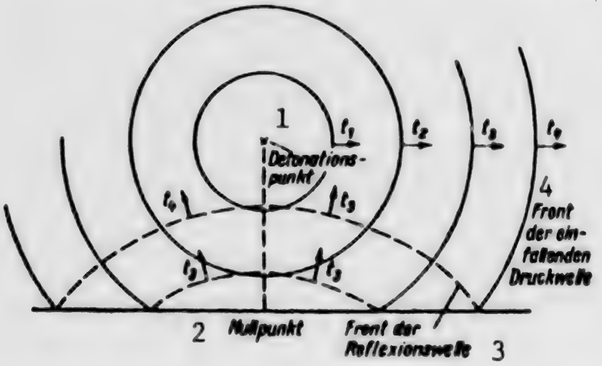


Figure 3.2. Formation of reflection wave. Key: 1--Detonation point; 2--Ground zero; 3--Reflection wave front; 4--Front of incident blast wave.

If the front of the blast wave, coming in from the detonation center, reaches the surface of the ground or the water, it is reflected and we get the reflection blast wave.

The formation of the reflection blast wave begins immediately as the front of the incident wave reaches the earth's surface. The air particles along the wave front are braked and are immediately reflected while additional air particles approach the earth's surface simultaneously with the incident blast wave. As a result of this there is a sudden compression of the air along the ground surface and this causes the density, pressure, and temperature in the reflection wave's front to rise. This means that overpressure in the reflection wave front is always higher than the pressure in the front of the incident wave. The absolute magnitude of the reflection pressure itself depends on the overpressure in the front of the incident wave and the angle incidence of the blast wave front with respect to the earth's surface. In the vicinity of ground zero, for example, the maximum pressure values in the reflection wave front are more than twice as high as the maximum values for the overpressure in the front of the incident blast wave.

This reflection of the incident blast wave along the ground surface is called regular reflection. It appears approximately in a circle around ground zero whose radius corresponds to the detonation altitude. This area is called the near zone.

There are two separate blast shocks (from the incident blast wave and from the reflection wave) which in the near zone affect objects above the surface of the ground. Objects on the surface of the ground only experience a pressure impulse whereby we get a maximum pressure which is practically equal to the reflection pressure.

Figure 3.3. Origin of reflection pressure along ground surface. Key: 1--Opposing directions of pressure propagation; 2--Incident wave; 3--Front of reflection wave; 4--Reflection wave; 5--Ground surface.

It has already been established that the reflection pressure is always higher than the maximum overpressure in the front of the incident blast wave. It follows from this that the front of the reflection wave is propagated at a relatively faster speed than the front of the incident wave. As a function of the distance + speed ratio between both wave fronts, the front of the reflection wave therefore will catch up with the front of the incident wave at a certain distance from ground zero; there is a superposition and a common wave front--the front of the main blast wave--is formed.

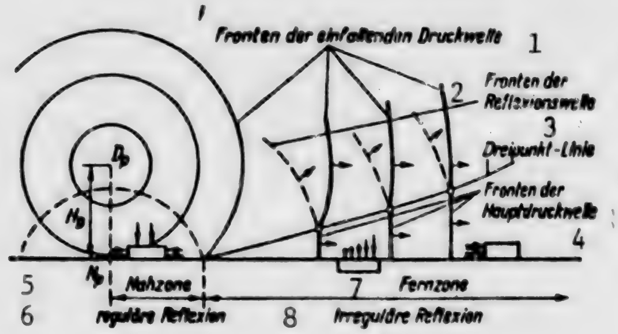


Figure 3.4. Formation of main blast wave. Key: 1--Fronts of incident blast wave; 2--Fronts of reflection wave; 3--Three-point line; 4--Fronts of main blast wave; 5--Near zone; 6--Regular reflection; 7--Far zone; 8--Irregular reflection.

This process is illustrated schematically in Figure 3.4 for the time shift in the blast wave fronts. Here it must be kept in mind that the formation of the main blast wave as a function of the detonation altitude and the detonation intensity naturally at a certain distance from ground zero first of all begins on the ground surface and continues in terms of height as the distance grows. The particular point, at which the three wave fronts coincide, is referred to as the triple point.

In three-dimensional terms, the triple points in their totality "form" a surface. All objects below this surface here are exposed only to a blast shock which is caused by the main blast wave.

This area of irregular reflection is called the far zone. The far zone terminates with the transition of the blast wave into the sound wave.

In the far zone, the destructive effects of the blast wave originate from the summary overpressure of the main blast wave. The main blast wave spreads with its almost perpendicular front along the earth's surface and leads to a particularly heavy pressure stress on vertical surfaces in installations on the earth's surface.

3.2.2. Air Blast Wave from Ground Detonation

It follows from what we said above that the irregular reflection of the blast wave starts all the more closely to ground zero the lower the detonation altitude happens to be. This is why, in case of a ground detonation, the blast wave is not formed in homogeneous air but as part of a close reciprocal interaction with the ground itself.

Because the detonation point and ground zero in fact coincide, the blast wave does not spread from the detonation center in a spherical shape but rather more or less in a hemispherical shape because there is little difference between direct propagation and reflection in terms of time.

The energy in the blast wave is distributed only over a "hemispherical" air volume. In a greatly simplified manner, this causes the doubling of the energy concentration compared to an air blast of equivalent intensity. In judging the propagation of the air blast wave deriving from ground detonations it is essential to note that the terrain relief here exerts far more influence than in the case of equivalent air blasts.

In addition we have the fact that light radiation heavily influences the propagation of the blast wave. The enormous heating of the ground leads to a reduction in the density of the air layer near the ground. The resultant faster propagation speed of the blast wave, compared to an air blast, causes a faster drop in the overpressure and thus a decisive reduction in the range of the blast wave as an annihilation factor.

It is furthermore typical that the blast wave in the proximity of the ground does not reveal any firmly outlined front and that the time span until the attainment of the pressure maximum can amount to several hundredths of a second.

In summary we can observe that the effect of the air blast wave from a ground burst exceeds the effect of an air blast in the immediate area around ground zero. But on the other hand the annihilation radii for certain objects are smaller.

It must however be pointed out here that these differences can often be neglected in rough calculations needed to prepare a situation estimate after enemy nuclear strikes, especially in the case of small and medium detonation intensities.

Exceptions consist only in the calculation of the annihilation radii for unprotected individuals and various technical combat equipment and buildings. Here we can have quite considerable differences.

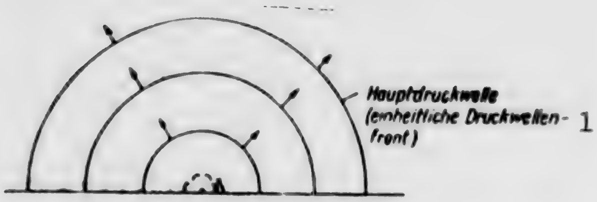


Figure 3.5. Propagation of blast wave from ground burst. Key: 1--Main blast wave (uniform blast wave front).

In case of a ground burst and, to a lesser degree, also in case of a low-altitude air burst, there is a reciprocal interaction between the air blast wave and the ground. In section 2.1.3. we covered the attendant crater formation in greater detail. Various waves are also propagated in the ground simultaneously with the air blast wave. They are broken down into seismic waves and ground pressure waves in terms of their origin and character. These phenomena will be covered in greater detail in Section 3.3.

3.2.3. Air Blast Wave from Underground Detonation

After underground detonations, the reciprocal interaction of the air blast wave with the earth naturally is even more pronounced than in the case of ground bursts. The intensity and range of the air blast wave from an underground detonation and thus also its possible annihilating and destructive effects change along with the detonation depth, other things remaining equal.

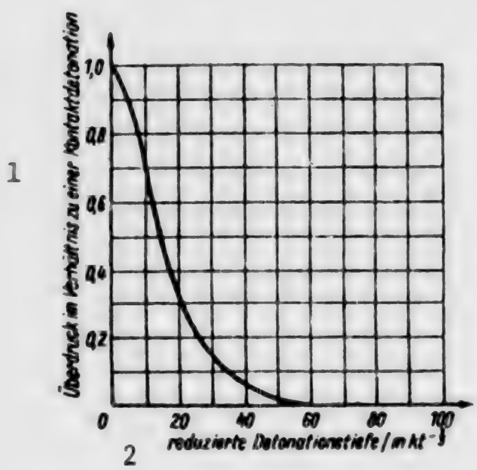


Figure 3.6. Relative overpressure values of air blast wave as function of detonation depth. Key: 1--Overpressure in relation to a contact detonation; 2--Reduced detonation depths, m $kt^{-1/3}$.

Starting at a certain detonation depth, both the effects of the air blast wave and the developing acoustic effects are completely insignificant. American nuclear weapon tests in tufa massifs indicate that the effects of the air blast wave can be neglected if the following applies to the reduced detonation depth[1]:

$$-H_r < 60 \quad \text{m kt}^{-1/3} \tag{3.1}$$

For example, in the light of the assumption made in 3.1, above, one can no longer by ear clearly detect the presence of a sound wave at a distance of 4 km from ground zero.

The graph above (Figure 3.6) illustrates the relative value of the air blast wave as a function of the detonation depth according to Violet[2]. The illustration shows that, in case of underground detonations at such depths which lead to optimum crater formation, there is a considerable weakening of the air blast wave.

3.2.4. Some Basic Laws of Air Blast Wave Propagation

3.2.4.1. Dependence of Blast Wave Parameter on Overpressure along Wave Front

Theoretical considerations as well as experimental investigations show that it is possible to illustrate the most important blast wave parameters as functions of the overpressure along the blast wave front.[3]

Because of the complicated propagation conditions involved in the air blast wave it is however required, for the sake of a simple and short description, to formulate certain restrictive criteria in this connection.

The following formulas apply on three conditions:

The blast wave propagation takes place under normal atmospheric conditions (undisturbed propagation, air pressure 760 mm Hg, temperature 15° C);

The formulas can be used in ground detonations both for the region of regular reflection and for the region of irregular reflection;

In case of air bursts, the formulas apply to the region of irregular reflection because, in the near zone, the angle of incidence of the blast wave front with respect to the ground surface exerts decisive influence.

There are additional restrictions for the individual formulas.

The following applies to the pressure wave parameters as a function of the overpressure along the wave front:

Blast wave velocity

$$D_f = 340 \cdot \sqrt{1 + 0{,}83\Delta p_f} \quad \mathrm{m\,s^{-1}} \tag{3.2}$$

Air speed along wave front

$$U_f = \frac{235\Delta p_f}{\sqrt{1 + 0{,}83\Delta p_f}} \quad \mathrm{m\,s^{-1}} \tag{3.3}$$

Air density along wave front

$$\varrho_f = 0{,}125\,\frac{6\Delta p_f + 7{,}2}{\Delta p_f + 7{,}2} \quad \mathrm{kp\,s^2\,m^{-4}} \tag{3.4}$$

Air temperature along wave front

$$T_f = 288\,\frac{(1 + \Delta p_f)\cdot(\Delta p_f + 7{,}2)}{6\Delta p_f + 7{,}2} \quad {}^\circ\mathrm{K} \tag{3.5}$$

Speed of sound along wave front

$$C_f = 340 \sqrt{\frac{(1 + \Delta p_f) \cdot (\Delta p_f + 7{,}2)}{6\Delta p_f + 7{,}2}} \quad \mathrm{m\,s^{-1}} \tag{3.6}$$

$$C_f = 20{,}1 \sqrt{T_f} \quad \mathrm{m\,s^{-1}} \tag{3.7}$$

Dynamic pressure (pressure head)

$$\Delta p_d = \frac{2{,}5\,\Delta p_f^2}{\Delta p_f + 7{,}2} \quad \mathrm{kp\,cm^{-2}} \tag{3.8}$$

Formula 3.8 can be used in this form only for values of the maximum overpressure along the blast wave front $\Delta p_r < 0{,}5$ kp/cm^{-2}. In case of higher overpressure values, it is necessary to introduce a coefficient allowing for the air's compressibility.

Reflection overpressure:

$$\Delta p_r = 2\Delta p_f + \frac{6\Delta p_f^2}{\Delta p_f + 7{,}2} \quad \mathrm{kp\,cm^{-2}} \tag{3.9}$$

Formula 3.9 presupposes that the blast wave front hits a motionless obstacle perpendicularly. We can see that in this case the reflection pressure values are between $2\Delta p_t$ (in case of small overpressure values) and $8\Delta p_t$ (in case of large overpressure values).

Table 3.1 is a compilation of some blast wave parameter values based on formulas 3.2 to 3.9. The restrictions formulated so far in this section apply fully in terms of content in the interpretation of the table.

Table 3.1. Dependence of the Most Important Blast Wave Parameters on Over-Pressure Δp_f along the Blast Wave Front

Δp_f kp cm^{-2}	D_f m s^{-1}	U_f m s^{-1}	C_f m s^{-1}	ϱ_f kp s^2 m^{-4}	T_f °K	Δp_d kp cm^{-2}	Δp_r kp cm^{-2}
0,000	340	0	340,0	0,1250	288,0	0	0
0,01	341	2,34	340,5	0,1258	288,8	$3{,}5 \cdot 10^{-5}$	0,020
0,05	347	11,5	343	0,1293	292	$8{,}6 \cdot 10^{-4}$	0,102
0,1	354	22,6	345	0,1335	296	$3{,}5 \cdot 10^{-3}$	0,208
0,5	404	99,2	360	0,165	321	$8{,}3 \cdot 10^{-2}$	1,20
1,0	460	174	377	0,201	351	0,322	2,75
5,0	772	518	471	0,381	552	6,92	22,3
10,0	1040	772	562	0,489	78[illegible]	21,4	54,8
50,0	2220	1800	1030	0,672	2650	177	362

Notes on Table 3.1:

The table clearly shows that, in case of high overpressure values, the air along the wave front can experience major temperature rises.

The dynamic pressure values exceed those of the maximum pressure along the wave front only in case of high overpressure values; this is why the dynamic pressure is of interest above all in the immediate area around ground zero.

In calculating the values for Δp_d, the air's compressibility was considered, in contrast to Formula 3.8.

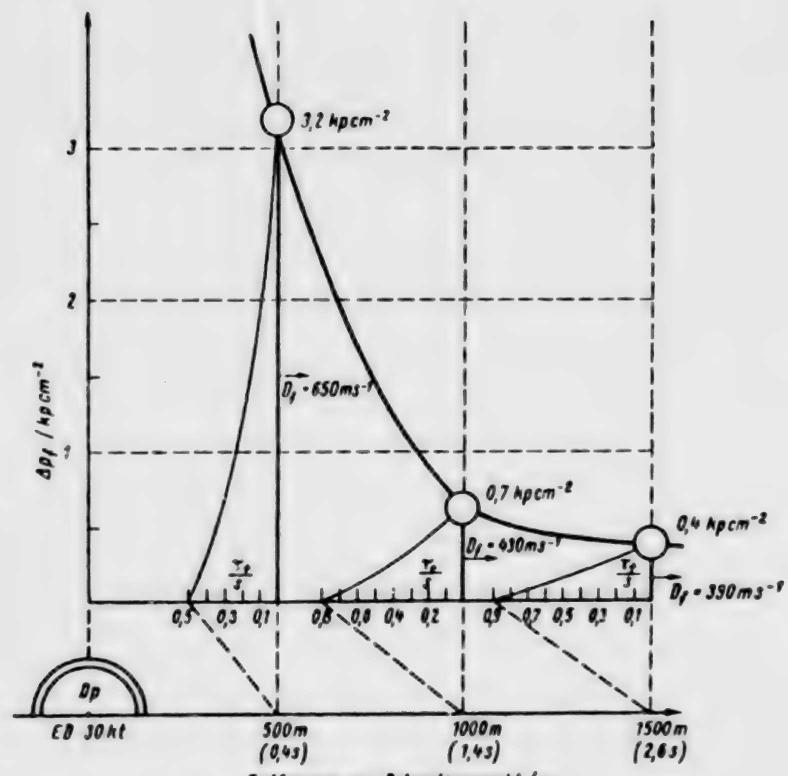


Figure 3.7. Change in some blast wave parameters as a function of the distance and the time connected with a 30-kt ground burst. Key: 1--Distance from detonation point, m.

The parameters given in Table 3.1 for the blast wave front decrease with time as the overpressure phase of the blast wave passes a particular place (point). The decline in the overpressure Δp and the dynamic pressure Δp_d during time τ_+ here can be characterized by the two empirical formulas:

$$\Delta p(t) = \Delta p_f \left(1 - \frac{t}{\tau_+}\right) \cdot e^{-\frac{t}{\tau_+}} \tag{3.10}$$

and

$$\Delta p_d(t) = \Delta p_d \left(1 - \frac{t}{\tau_+}\right)^2 \cdot e^{-\frac{2t}{\tau_+}} \tag{3.11}$$

Figure 3.7 shows that the maximum overpressure Δp_f decreases relatively quickly with the distance. The speed of the blast wave front also decreases constantly. As the distance increases, the action duration of the overpressure phase τ_+ increases.

The blast wave front will pass a point 500 m from the place of detonation at a speed of D_t = 650 m sec^{-1} 0.4 sec after the detonation. The maximum overpressure along the blast wave front Δp_f 3.2 kp cm^{-2} here is again reduced at this range during the action time of the overpressure phase τ_+ = 0.5 sec to the normal atmospheric air pressure, that is to say, at this point the overpressure phase acts upon an object during a time span of 0.4-0.9 sec after the detonation. Similar considerations result for the ranges of 1,000 m and 1,500 m from the place of detonation.

3.2.4.2. The Blast Wave's Similarity Law

The analysis of a nuclear weapon detonation yields special values for each special case. In practice however it is important to be able to draw conclusions from a detonation, carried out with a certain detonation intensity, with respect to the effects of other detonations with different detonation intensities. This possibility exists in the formulation and use of certain similarity laws.

For the blast wave deriving from a nuclear weapon detonation, the similarity law can generally be formulated as follows:

For two detonations with detonation intensities q_1 and q_2, which are triggered under otherwise equal conditions, the blast wave parameters at distances r_1 and r_2 from the detonation center are equal. Here, r_1 and r_2 are connected with q_1 and q_2 through the relationship:

$$\frac{r_1}{r_2} = \left(\frac{q_1}{q_2}\right)^{1/3} \tag{3.12}$$

Equation 3.12 shows that the annihilation radii of the blast wave grow considerably more slowly than the detonation intensity of the nuclear weapons. For two detonation intensities, which are in a ratio of 8:1 to each other, the radii of equal effect are only in a ratio of 2:1. This means, in other words, that the doubling of the action radii calls for an eight-fold increase in the detonation intensity.

Assuming that we select, as comparison equivalent, a nuclear weapon with q = 1 kt, relation 3.12 is simplified as follows:

$$r = r_{1\,kt} \cdot q^{1/3} \quad m \tag{3.13}$$

$r_{1\,kt}$--Distance during nuclear weapon detonation with an intensity of 1 kt at which the blast wave parameters have certain values;
r--Distance at nuclear weapon detonation with an intensity of q kt where the blast wave parameters reveal the same values.

The two last-named formulas can be used only on the assumption that the distances r are related to the detonation point because the blast wave parameters, as a function of the detonation intensity, are not only a function of the distance but also of the detonation altitude.

In order to be able to relate the distances to ground zero also in air bursts, it is a good idea to introduce the concept of equivalent detonation altitude. In keeping with the similarity law for the blast wave, we get the following simple expression here:

$$\text{equivalent detonation altitude} = \frac{\text{Actual detonation altitude}}{q^{1/3}} \tag{3.14}$$

It follows from this relationship that the similarity law of the blast wave can be applied to two detonations with intensities q_1 and q_2 both for the distances from the detonation point and from ground zero if both detonations have the same equivalent detonation altitude. The derivation for this is given below for the sake of better understanding.

From the definition of the equivalent detonation altitude, we get the following for two detonations with intensities q_1 and q_2 at detonation altitudes H_{D1} and H_{D2} with an equivalent detonation altitude of $H_{D_{squ}}$:

$$H_{D_{squ}} = \frac{H_{D_1}}{q_1^{1/3}} = \frac{H_{D_2}}{q_2^{1/3}}$$

In conjunction with the blast wave's similarity law, it follows from this that:

$$\frac{H_{D_1}}{H_{D_2}} = \frac{q_1^{1/3}}{q_2^{1/3}} = \frac{r_1}{r_2} = \frac{r_{0_1}}{r_{0_2}}$$

if r_{0_1} and r_{0_2} are the particular distances from ground zero.

In analogy to Formula 3.13, assuming we have equivalent detonation altitudes and a reference equivalent of 1 kt, we get the following relationship for the radii of equal blast wave parameters, related to the particular ground zero:

$$r_0 = r_{0_{1\,kt}} \cdot q^{1/3} \quad m \tag{3.15}$$

3.2.4.3. Change in Maximum Overpressure along Blast Wave Front as Function of Detonation Altitude and Distance from Ground Zero

The blast wave parameters from a nuclear weapon detonation are a function of the detonation intensity, the detonation altitude, and the distance from ground zero (distance from detonation center). As a result of nuclear weapon tests conducted as well as on the basis of theoretical investigations, a series of laws was formulated for the computation for the most important characteristic magnitude. A look at the pertinent formulas however shows that their handling is rather complicated because of numerous restricting conditions and that their practical application is often very laborious.

This is why we will in the following proceed in such a manner that reference will be made to the corresponding values from a detonation of a nuclear weapon with an intensity of 1 kt and that a conclusion will be drawn to analogous magnitudes deriving from other detonation intensities through the use of the blast wave's similarity laws. This kind of approach is not particularly accurate but it is in most cases enough for rough calculations used for guidance.

Figure 3.8 shows the change of maximum overpressure along the blast wave front deriving from a ground burst with an intensity of 1 kt as a function of the distance from the detonation center. The values relate to a detonation on level ground under normal weather conditions at sea level.

The way to use the diagram in Figure 3.8 emerges from the following example.

Problem: Determine the distance from the detonation center at which, after an 8-kt ground burst, we get a maximum overpressure along the blast wave front amounting to 0.2 kp/cm^{-2}.

Solution: From the diagram we can read off that, at a detonation intensity of 1 kt, the overpressure Δp_f = 0.2 kp/cm^{-2} appears at a distance of 600 m from the detonation center. With the help of Formula 3.13 we can calculate the equivalent distance for a detonation intensity of 8 kt at 1,200 m. For similar rough calculations connected with air bursts, considering the detonation altitudes, we have the diagrams in figures 3.9 and 3.10.[4] The use of the diagrams will also be explained with the help of an example.

Problem: Determine the distance from ground zero r_0 where, following an air burst with an intensity of q = 8 kt, at a detonation altitude of H_D = 150 m, we get a maximum overpressure 0.3 kp/cm^{-2} along the air blast wave front.

Solution: From Formula 3.14 we can calculate the equivalent detonation altitude; it corresponds to the detonation altitude from an air burst with an intensity of q = 1 kt and it comes to 75 m. From the diagram in Figure 3.10 we can read off that, in case of q = 1 kt and H_D = 75 m, the overpressure Δp_f = 0.3 kp/cm^{-2} will appear at a distance of r_0 = 600 m from ground zero. In case of need, the intermediate values must be interpolated in a rough fashion. From relationship 3.15 it follows finally, for the distance from ground zero at q = 8 kt, where Δp_f = 0.3 kp/cm^{-2} is applicable, that we have r_0 = 1,200 m.

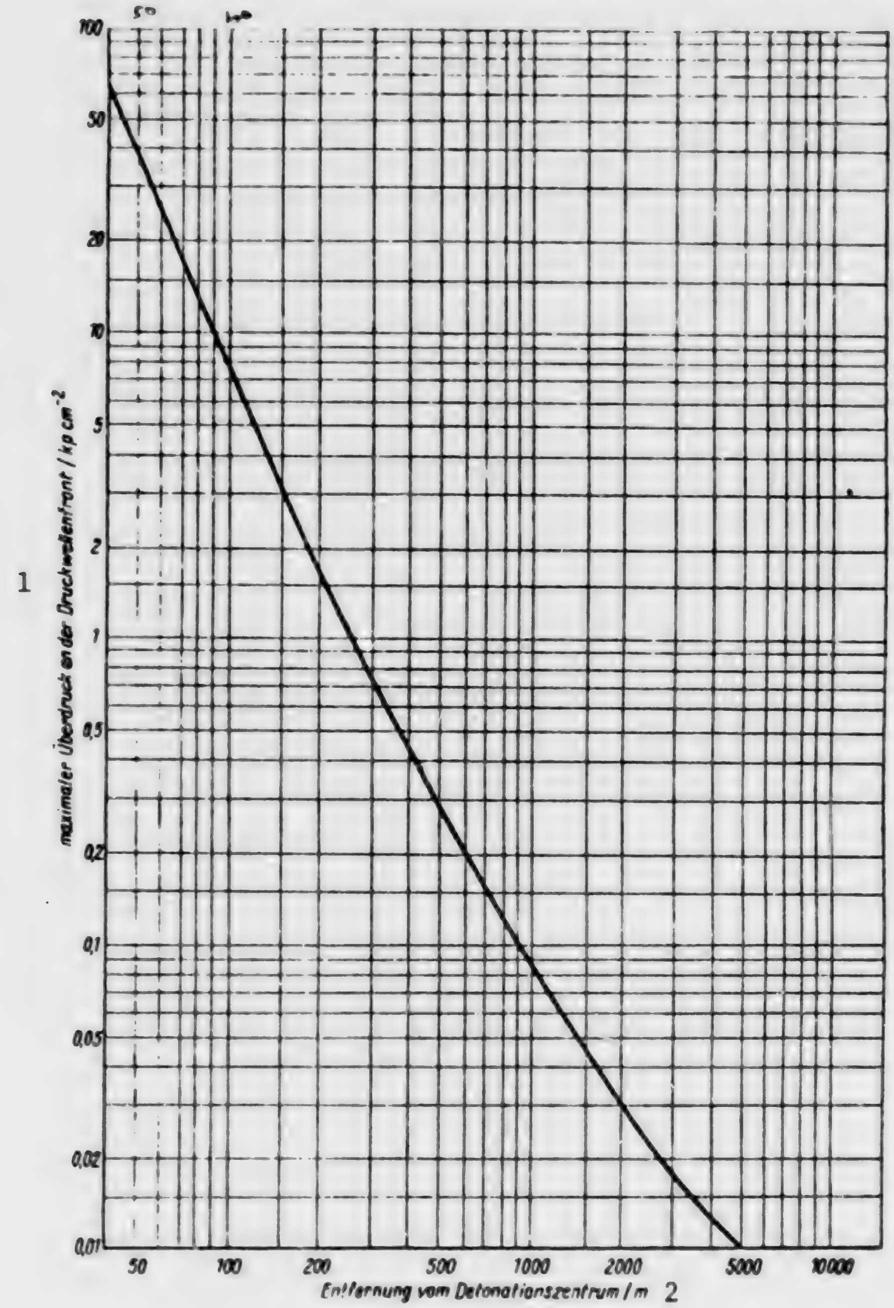


Figure 3.8. Maximum overpressure along air blast wave front as function of distance deriving from 1-kt ground burst.[4] Key: 1--Maximum overpressure along blast wave front, kt cm^{-2}; 2--Distance from detonation center, m.

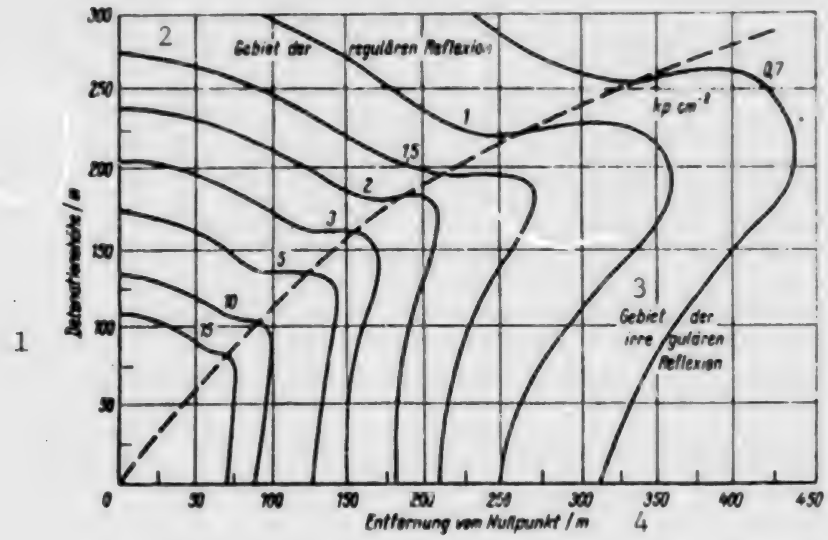


Figure 3.9. Maximum overpressure along air blast wave front as function of distance from ground zero and detonation altitude after 1-kt air burst (range of overpressure Δp_f from 0.7 kp cm^{-2} to 15 kp cm^{-2}). Key: 1--Detonation altitude, m; 2--Region of regular reflection; 3--Region of irregular reflection; 4--Distance from ground zero, m.

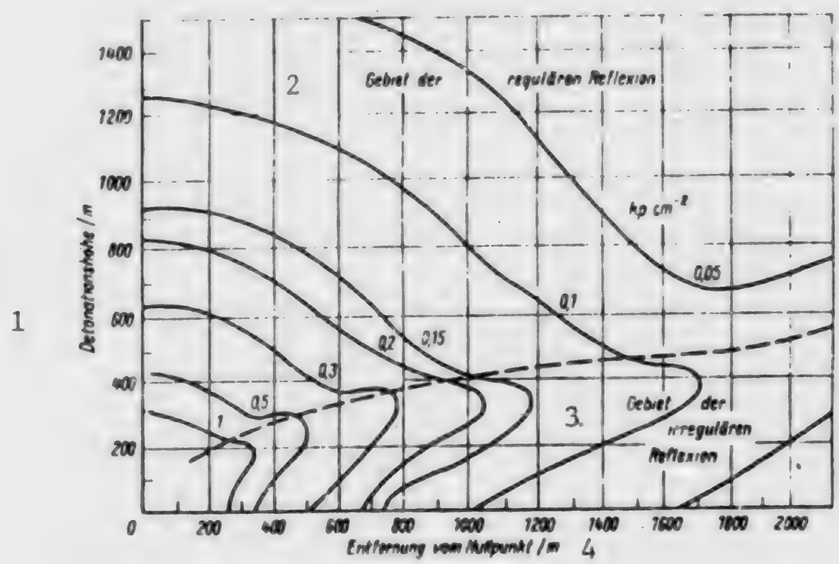


Figure 3.10. Maximum overpressure along air blast wave front as function of distance from ground zero and detonation altitude after 1-kt air burst (range of overpressure Δp_f from 0.05 kp cm^{-2} to 1.0 kp cm^{-2}). Key: 1--Detonation altitude, m; 2--Region of regular reflection; 3--Region of irregular reflection; 4--Distance from ground zero, m.

The diagrams given show that--after air bursts, for each value of overpressure Δp_t--there is a certain detonation altitude at which the distance from ground zero r_0, up to which this overpressure appears, will reach its maximum.

This altitude is referred to as the optimum detonation altitude. It is a function of the detonation intensity and the minimum destruction pressure needed to hit a target.

If we express the minimum destruction pressure or the corresponding overpressure along the blast wave front, required to hit a target, by the factor k, then, on the basis of the similarity law of the blast wave for detonation intensities $q \neq 1$, the following relationship applies approximately for the determination of the optimum detonation altitude:

$$H_{D_{opt}} = k \cdot q^{1/3} \quad \text{m} \tag{3.16}$$

What we have said so far shows that, in addition to the detonation intensity, the detonation altitude also exerts decisive influence on the size of the destruction area in a certain target.

Generally, one can establish, by way of confirmation of what we said in section 2.2.2, that the detonation altitude for a nuclear weapon with detonation intensity q will be selected all the lower, the higher the hardness of the target to be hit happens to be.

The biggest destruction is caused in case of a ground burst in the area around ground zero; at greater distances however the maximum values for the overpressure along the blast wave front are below those which appear at the same distances following air bursts. This fact is once again clearly shown by the numerical values in Table 3.2.

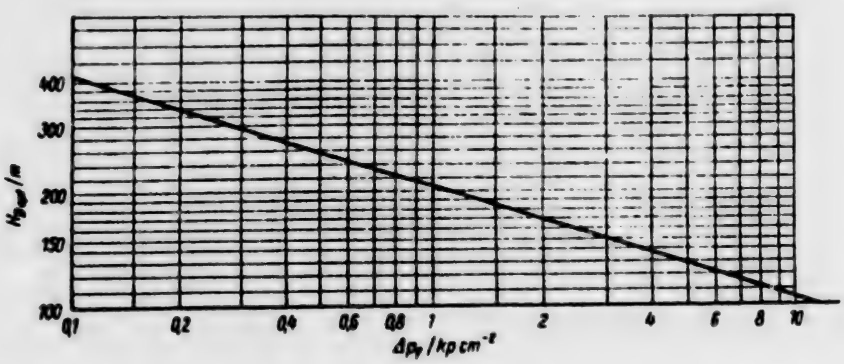


Figure 3.11. Optimum detonation altitudes for nuclear weapon with detonation intensity q = 1 kt as function of overpressure Δp_f leading to the destruction or damage or annihilation of a certain object.

Table 3.2. Maximum Overpressure Δp_f along Blast Wave Front for Detonation Intensity q = 1 kt for Various Detonation Altitudes

Entfernung vom Nullpunkt m	Detonationshöhe/m $H_D = 0$	$H_D = 100$	$H_D = 200$	$H_D = 300$
	Überdruck an der Druckwellenfront/kp cm^{-2}			
50	40	13	2,8	1,3
100	6,5	8,5	2,2	1,0
200	1,8	2,0	1,7	0,8
300	0,8	0,9	1,3	0,7
400	0,5	0,6	0,9	0,6
500	0,3	0,4	0,6	0,5
600	0,2	0,3	0,4	0,4
700	0,15	0,2	0,3	0,3
800	0,12	0,18	0,2	0,28
900	0,10	0,15	0,19	0,24
1000	0,08	0,14	0,17	0,20

Key: 1--Distance from ground zero; 2--Detonation altitude, m; 3--Overpressure along blast wave front, kp cm^{-2}.

For other blast wave parameters, such as the dynamic pressure, the action time of the blast wave, and the arrival time of the blast wave front, we can entertain similar considerations and carry out similar calculations, that is, similar to those presented in this section for the overpressure along the blast wave front. But because more detailed treatment is not possible in the space available to us, we would like to refer to the bibliographic references given.

3.2.4.4. Reflection Overpressure as Blast Wave Front Hits Obstacle

The maximum overpressure Δp_f, appearing after the detonation of a nuclear weapon with detonation intensity q and distance r_0 from ground zero along the blast wave front can only be indirectly used in judging the anticipated destruction in a certain object. This is due to the fact that the blast wave front is braked on hitting an obstacle as a result of which a certain reflection overpressure Δp_t develops along the object surface facing toward the blast wave front. Here the ratio between the reflection overpressure Δp_f and the overpressure along the blast wave front Δp_f depends on the magnitude of the overpressure along the blast wave front and the blast wave's angle of incidence.

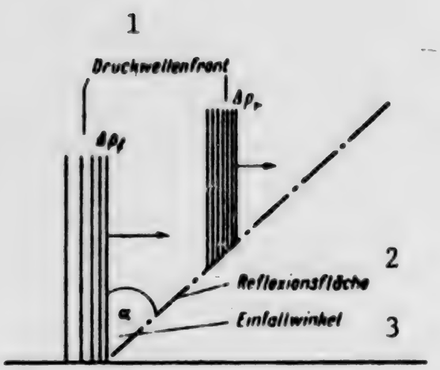


Figure 3.12. Simplified illustration of origin of reflection overpressure Δp_f along the surface of an installation. Key: 1--Blast wave front; 2--Reflection surface; 3--Angle of incidence.

For an angle of incidence $\alpha = 0°$, that is to say, if the blast wave front hits the surface of an obstacle perpendicularly, the ratio $\Delta p_r : \Delta p_f$ for the values of the overpressure in the blast wave front $\Delta p_f \leq 1\ \mathrm{kp\,cm^{-2}}$ is on the order of 2 to 3 but, as the values grow bigger, it keeps growing from Δp_f (see also Formula 3.9).

In the far zone, that is to say, the zone of irregular reflection, in which the front of the main blast wave is propagated in fact perpendicularly to the earth's surface, the reflection overpressure is overwhelmingly expressed as lateral pressure against the vertical surfaces of buildings and installations.

Figure 3.13 schematically illustrates the pressure stresses on an above-ground installation at a distance of 1 km from ground zero after a nuclear weapon detonation with an intensity of q = 20 kt at an altitude of 600 m. The overpressure along the blast wave front at this range is about 0.9 kp cm^{-2}; when $\alpha = 0°$, we have the ratio $\Delta p_r : \Delta p_f \approx 2{,}7$.

In conclusion it might be observed that exact calculations of the pressure stresses on various buildings and installations as well as other objects are rather laborious. This is why, under field conditions, one usually works with guidance values which, under the existing conditions, make it possible to estimate the anticipated destruction or the shelter condition with adequate accuracy. For further study, reference is made to some publications in the magazine MILITAERTECHNIK.[5]

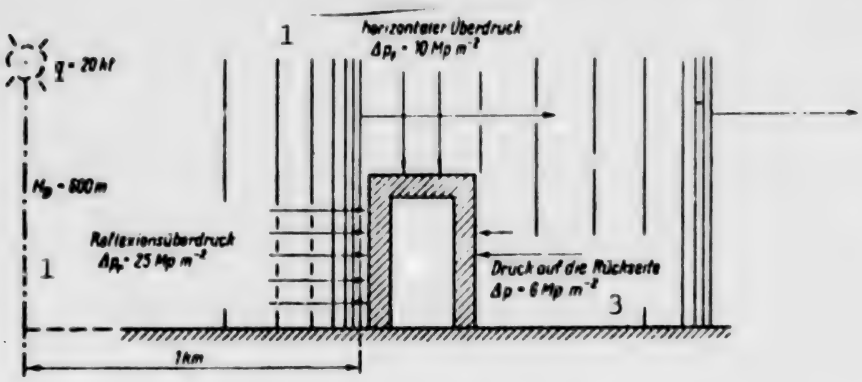


Figure 3.13. Effect of Blast Wave on Surface of Above-Ground Installations. Key: 1--Reflection overpressure; 2--Horizontal overpressure; 3--Pressure on reverse side.

3.2.5. Factors Affecting Air Blast Wave Propagation

Our past considerations of some parameters in the air blast wave always started with the assumption that this wave was able to spread undisturbed in homogeneous air.

In judging the annihilating effects of a nuclear weapon detonation however it is important to know that there are some factors which do have an effect on air blast wave propagation and which thus influence also the character and the scope of destruction.

Because the purpose of this study does not permit a comprehensive treatment of this problem complex below, we will present some elementary comments concerning the influence of light radiation, the terrain relief, as well as weather conditions.

3.2.5.1. Effect of Light Radiation.

Light radiation can have a very great influence on the blast wave parameters. Due to its action, grass, foliage, as well as organic substances in the ground are burned up in the area around ground zero; cracks are formed, the air layer near the ground is enriched with dust due to the severe drying effect and thus in turn absorbs a large part of the light radiation.

In this way, the temperature in the air layer near the ground reaches values of several thousand degrees in case of light impulses amounting to several hundred cal cm^{-2}. The heated air layer can have a thickness of between several meters and several tens of meters.

Up to the entry into the heated air layer, the blast wave has the same parameters as in case of a detonation in homogeneous atmospheres. But as the blast wave front reaches the heated air layer, the wave front's movement speed increases and the blast wave is broken. This again causes the blast wave's angle of incidence to grow. This situation is illustrated schematically in Figure 3.14.

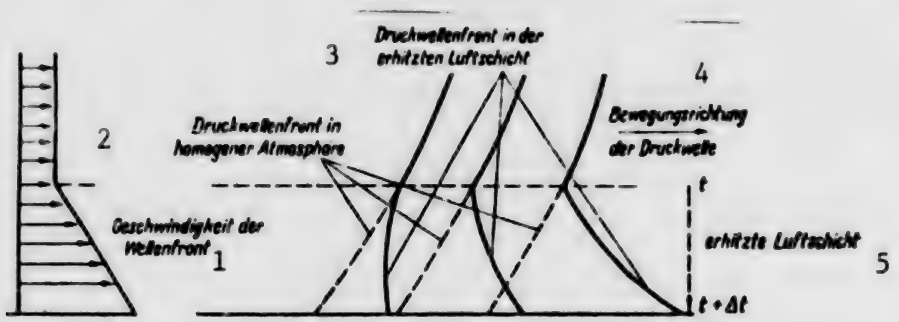


Figure 3.14. Origin of blast wave anomaly after severe heating of air layer near ground due to light radiation. Key: 1--Wave front speed; 2--Blast wave front in homogeneous atmosphere; 3--Blast wave front in heated air layer; 4--Direction of motion of blast wave; 5--Heated air layer.

Because the air temperature and thus also the speed of the wave front in the air layer near the ground decrease with growing altitude above the surface, the forward boundary of the blast wave takes on the shape of a wedge.

This phenomenon yields three peculiarities which are combined under the term "blast wave anomaly":

The overpressure in one particular place does not rise suddenly as the blast wave front reaches it but instead goes up gradually until it reaches a maximum;

The maximum overpressure values are considerably below the pressure values which appear when this kind of heating of the air layer near the ground is missing;

The movement speed of the air in the blast wave front is faster than under similar conditions in a homogeneous atmosphere.

The biggest anomaly of the blast wave appears at a distance which corresponds to the detonation altitude. Here, the time, in which the pressure reaches its maximum, can reveal the value $\Delta t = (0{,}1 \div 0{,}3)\tau_+$.

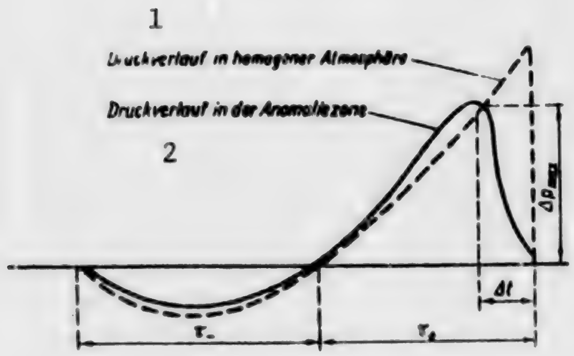


Figure 3.15. Change in pressure curve following severe heating of air layer near ground due to light radiation. Key: 1--Pressure curve in homogeneous atmosphere; 2--Pressure curve in anomaly zone.

The size of the maximum overpressure can be 50 percent and more below the pressure values which appear when there is no heating of the air layer near the ground. The dynamic pressure rises considerably at the same time.

For example, if the air layer near the ground is heated by 1,000-2,000° C, a dynamic pressure of about 1.0-1.5 kp cm^{-2} will correspond to a maximum overpressure of $\Delta p_{max} =$ 1.1 kp cm^{-2} in the blast wave front whereas the corresponding dynamic pressure in homogeneous air would only be 0.35 kp cm^{-2}.

By way of summary we can say, concerning the effect of the blast wave in the anomaly zone, that--because of the gradual pressure rise and the lower maximum overpressure values--kettle-shaped attachments [boiler-shaped fastenings] were destroyed to a lesser extent in case of the absence of the anomaly. But because the movement speed of the air masses in the anomaly zone and thus the dynamic pressure rise, the annihilation radii for troops quartered out in the open differ only negligibly from those found in case of the absence of severe heating of the air layer near the ground. Nevertheless, it is especially the blast wave anomaly which is suitable for illustrating the limitations of simple rough calculations for the annihilating effect of the blast wave.

3.2.5.2. Influence of Terrain

The terrain relief, its layout, vegetation cover and built-up portions can likewise considerably influence the size of the blast wave parameters as well as their change with the distance from ground zero.

Because in the considerations to be entertained here we are primarily concerned with practical conclusions, one must however always keep in mind the ratio between the detonation altitude and the elevation of the existing rises in the particular terrain and one neither overestimates nor underestimates the influence of the terrain.

One can in practical terms speak of a pressure rise along the forward slope and a pressure decline along the reverse slope only if the inclination angle of the slopes is at least 5-10°. If the blast wave moves across hilly and heavily-cut terrain, then it is reflected by the forward slopes or it flows around these rises from the side and penetrates into the gorges and valleys.

Because of that, the blast wave parameters, especially the overpressure values, will differ essentially from those encountered under otherwise equal conditions in level terrain. One must in particular also expect that the speed and movement direction of pressure propagation will deviate greatly from the radial movement.

After an air burst, the size of the maximum overpressure depends primarily on the distance from the detonation point (ground zero) and the angle of incidence of the blast wave with respect to the earth's surface. Because the blast wave from an air burst in the near zone, especially in the region

around ground zero, however comes in more or less perpendicularly with respect to the ground surface, it follows that the angle of incidence has an only relatively minor effect on the maximum overpressure in the reflection front wave and that the nature of the terrain thus has little influence on the annihilating effects of the blast wave. Conditions are different in the far zone because, due to the irregular reflection, the blast wave here is propagated along the surface of the ground with a practically vertical front. This is why the blast wave runs into the forward slopes of the elevations and again flows into the valleys over the reverse slopes.

Table 3.3. contains some rough guidance values on the pressure rise or pressure drop along a slope facing toward the detonation (forward slope) or along the slope facing away from the detonation (reverse slope) for various inclination angles for the far zone (zone of irregular reflection).

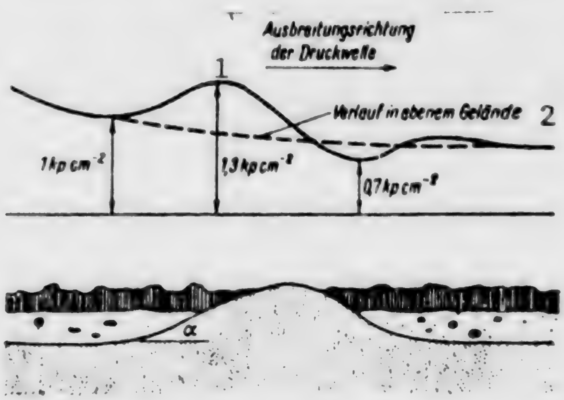


Figure 3.16. Influence of terrain relief on maximum overpressure along blast wave front.[6] Key: 1--Blast wave propagation direction; 2--Course in level terrain.

Table 3.3. Guidance Figures on Influence of Terrain Relief upon Pressure Rise or Pressure Drop in Zone of Irregular Reflection Compared to Propagation of Air Blast Wave over Level Terrain

1 Neigungswinkel	2 Korrekturfaktoren 3 Vorderhang	Hinterhang 4
$10^\circ < \alpha \leq 15^\circ$	1,25	0,8
$15^\circ < \alpha \leq 30^\circ$	2	0,7
$\alpha = 45^\circ$	2,5	0,5

Key: 1--Inclination angle; 2--Correction factors; 3--Forward slope; 4--Reverse slope.

In this way, we can get overpressure values which deviate considerably from each other in heavily-cut terrain at equal distances from ground zero. This is why the destruction surface under these conditions will likewise not be strictly circular. While mountains or ridges facilitate a reduction of the distances of equal effect in relation to level terrain--the pressure rise appears along the forward slope and the effect is less only along the reverse slope--the pressure wave can spread more powerfully along the valleys and thus move over greater distances.

This effect of the terrain relief naturally will be all the more powerful, the more the terrain is broken up and the lower the detonation altitude happens to be. This is why the influence of the terrain on the blast wave parameters is considerably greater after ground bursts than after air bursts.

Concerning vegetation cover, we are primarily interested here in woods. Woods constitute an obstacle to the movement of air masses and weaken the effect of the blast wave. But because the trees have an only relatively short height, the maximum overpressure within the forest differs only little from the maximum overpressure along the blast wave front which spreads over the forest. The immediate effects of the blast wave in far-flung and vast forests are reduced nevertheless; this is due to the fact that the movement of the air masses in the blast wave is severely braked and that the dynamic pressure therefore drops quickly.

If the overpressure in the blast wave front is less than 0.3-0.5 kp/cm^{-2}, then, for example, the air's motion speed at a distance of 50-100 m from the edge of the woods--if the detonation takes place outside the woods--can be several times smaller than in open terrain.

If the overpressure is more than 0.3-0.5 kp/cm^{-2}, then the blast wave will break or uproot trees and this can be the cause of indirect blast wave damage.

The blast wave parameters change very considerably in case of detonations over cities and villages, in other words, in built-up terrain. Here the influence on the blast wave depends on the density of the buildup pattern, the height of the buildings, and their position with respect to each other.

The maximum overpressure, which acts upon the walls of the buildings facing toward the detonation center, is determined by the magnitude of the overpressure in the blast wave front (which would appear at this distance if the terrain were not built up) and the ratio of the distance between the buildings and the building height as such.

A detailed description of this problem complex is extraordinarily complicated and this is why we will only give some guidance values here.

At an overpressure of $\Delta p_f < 1\ kp/cm^{-2}$ along the blast wave front, the pressure along the front wall of the rear building is reduced roughly by a factor of 0.7 if the interval between the buildings is roughly equal to the building height.[7] If the interval between two buildings is more than four times the average building height, then the buildings will practically no longer offer each other any protection worth mentioning.

Because of the differing position of the buidings with respect to the blast wave front propagation direction, the influence of the buildup density, the various building and installation hardness degrees, and a series of other factors, it is possible to pursue theoretical considerations for the purpose of estimating the anticipated destruction only with a relatively big effort.

This is why the corresponding viewpoints regarding the operations of military units and the necessary defense measures will be covered in greater detail along with the description of the annihilating effects of the blast wave.

3.2.5.3. Influence of Meteorological Factors

Among the meteorological factors, it is especially the wind and the temperature stratification which exert a certain influence on the propagation of the blast wave and its parameters. Compared to the other factors, they however have an only relatively minor effect and they are of significance only at greater distances from ground zero (in case of detonations with a detonation intensity of $q < 100$ kt at distances of $r > 10$ km).

In case of convective air layers (Figure 3.17a), the blast wave will rise from the ground as the distance from ground zero grows. This causes the overpressure in the air layer near the ground to drop.

In case of an inversive temperature stratification of the air (Figure 3.17b) on the other hand the blast wave is almost pressed against the earth's surface. Because of that, the overpressure values at the corresponding distances from ground zero are somewhat higher than under normal conditions.

The influence of the wind on the blast wave's propagation consists in the fact that there can be a rise in the overpressure along the side facing away from the wind and a corresponding drop along the side facing toward it (Figure 3.17c). Due to the big differences between the speed of blast wave propagation and the wind velocity--even in case of high wind velocities--however the changes in the overpressure values are only on the order of magnitude of several percent and they are therefore not of interest in any semistrategic estimates.

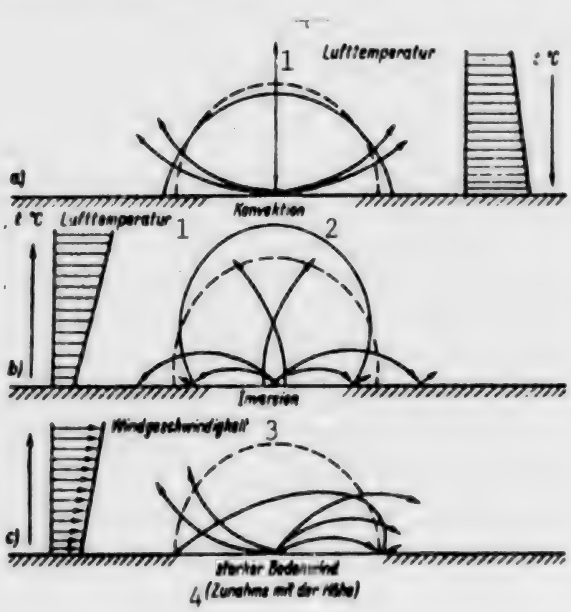


Figure 3.17. Air blast wave propagation as function of meteorological conditions. Key: 1--Air temperature; 2--Convection; 3--Wind velocity; 4--Strong surface wind (increase with altitude).

Review Questions

3.4. Explain the terms "incident blast wave, reflection blast wave, and main blast wave."

3.5. What physical phenomena are responsible for the pressure rise connected with the reflection of the incident blast wave along the earth's surface during the formation of the reflection blast wave?

3.6. Why is there a superposition of the fronts of the incident blast wave and the reflection blast wave toward the main blast wave front after air bursts at a certain distance from ground zero and why does the height of the main blast wave front above the ground surface increase with growing distance from ground zero?

3.7. Wherein resides the practical significance of the subdivision of the air blast wave's action range into a near zone and a far zone?

3.8. What are the essential features that distinguish the formation and propagation of the air blast wave after surface and underground bursts from those after air bursts?

3.9. What conclusions can be derived from the general dependence of the blast wave parameters on the maximum overpressure along the blast wave front, (see Table 3.1)?

3.10. Explain the similarity law of the blast wave and its application in air and ground bursts.

3.11. What do we mean by the term optimum detonation altitude?

3.12. What viewpoints result from a consideration of the reflection overpressure regarding the effect of the air blast wave on above-ground installations, installations partly built into the ground, and those installations which end at the earth's surface, regarding the near and far zones?

3.13. Explain the essence of the blast wave anomaly. Wherein resides its practical significance in preparing a situation estimate after enemy nuclear weapon strikes?

3.14. What are the conclusions deriving from the reciprocal interaction between the air blast wave and the terrain for optimum exploitation of the terrain's protective properties when it comes to quartering and moving troops?

3.15. The action effect surfaces of nuclear weapon strikes are usually plotted on the map in a circular form. Under what conditions must one absolutely subsequently consider the influence of the terrain when preparing a situation estimate.

3.3. Blast Wave Propagation in Ground

As we hinted earlier in Section 3.2.2, a part of the pressure energy is propagated in the ground after ground and underground detonations. The waves which are being propagated in the ground are distinguished, in keeping with their origin and their character, as seismic waves and earth pressure waves.

Seismic waves spring from the detonation center and originate due to the immediate effect of the detonation on the surrounding earth or rock and the pressure propagation in the ground.

Ground pressure waves are formed due to the action of the air pressure wave upon the ground. They are propagated primarily from the earth's surface into the depth. Due to the reflection of waves during the transition from the ground to the air and viceversa as well as along different types of rock layers in the depth of the earth, calculations of the pressure conditions in the earth layer near the surface are rather complicated.

Seismic waves and earth pressure waves can be superposed upon each other and can thus bring about both a pressure rise and a pressure drop.

As a result of an underground detonation and also, to some extent, after a ground burst, there is an acceleration and a shifting of the earth material. The ground is deformed. Tensions and vertical uplifts develop as a function of the detonation conditions and the geological structure of the detonation area.

To get an idea of the order of magnitude of these effects after underground detonations, Table 3.4 contains some data on test detonations. It must be kept in mind that the detonations mentioned were conducted at very great detonation depths.

Table 3.4. Zone of Destruction of Entry Tunnels after Different Detonations of Varying Intensity in Tufa[8]

2 Größe der Deformierung	3 Versuchsdetonationen »Blanka« 19 kt 255 m¹)	»Logan« 5 kt 253 m¹)	»Rainier« 1,7 kt 240 m¹)	»Neptun« 0,115 kt 30 m¹)
4 durchgehende Zerstörung	260 m	250 m	60 m	21 m
5 Ausbruch von Gesteinsbrocken	–	–	150 m	47 m

Key: (1) These numbers indicate the depths at which the nuclear charges were placed; 2--Magnitude of deformation; 3--Test detonations; 4--Continuing destruction; 5--Breakout of rock chunks.

To estimate the destruction of tunnels after underground detonations in tufa in similar rock massifs, we can work with the following approximation formulas.

We must expect the tunnel to collapse up to a distance of:

$$r = 100 \cdot q^{1/3} \quad m \tag{3.17}$$

No destruction is to be expected at distances of:

$$r = 200 \cdot q^{1/3} \quad m \tag{3.18}$$

A comparison of the "Blanka" and "Logan" detonations (Table 3.4) however clearly shows that the use of the similarity laws can lead to very big mistakes. The particular geological structure obviously has an extraordinarily strong effect here.

The test detonations conducted furthermore showed that the acceleration of the ground changes roughly proportionally in the form of r^{-4} with the distance from the detonation center.

In the "Rainier" detonation, for example, the acceleration 60 m below the surface in the direction toward ground zero was about 1 g and it went up immediately along the earth's surface to 5.8 g as a result of reflection. The radial or tangential tensions 30 m away from the detonation center were 70 kp cm^{-2} or 50 kp cm^{-2}. They decreased in proportion in terms of r^{-3}.

Of special interest are the seismic effects along the earth's surface. The size of the shift amplitude is of the utmost significance regarding the effect on above-ground building structures. After the "Blanka" test, the amplitude of the vertical shift reached a value of 0.75 m within 0.4 sec. After the "Rainier" detonation, the upper part of the mountain slope was separated from the massif at a depth of 30-90 m and during an interval of 146 msec it shifted upward with a maximum amplitude at ground zero amounting to 0.3 m.

In the case of the "Gnome" detonation (3 kt, 305 m, sand and porous sandstone), there was a vertical uplift of 1.8 m. These vertical uplifts grow as the detonation intensities go up and as the detonation depths decrease. Under field conditions of course it is above all underground detonations with crater formations that are significant. In this case, a certain part of the detonation energy escapes into the atmosphere while the earth above the nuclear charge is completely lifted off and there are also big vertical uplifts of the earth in the area around the developing crater. Data worthy of generalization however are not yet present in the available literature.

According to Carder and Cloud[9], the horizontal shift of the earth's surface in the case of tufa and similar rocks can be calculated according to the following approximation formulas for the case of underground nuclear weapon detonations.

The following applies for distances of 0.3-3 km from the detonation center:

$$A = 3{,}4 \cdot \frac{q^{0.75}}{r^2} \cdot 10^3 \quad \text{cm} \tag{3.19}$$

The following applies for distances of 3 km to 150 km from the detonation center:

$$A = 13 \cdot \frac{q^{0.75}}{r} \cdot 10^{-(4+0{,}006r)} \quad \text{cm} \tag{3.20}$$

Caution! In contrast to general statements, it is necessary to insert in both formulas the detonation intensity q in tons (t) and the distance from the detonation center in Formula 3.19 in meters (m) and in Formula 3.20 in kilometers (km).

Because of the seismic effects deriving from underground detonations, those objects on the earth's surface which are not located directly in the area around ground zero are also in danger. These effects greatly depend on whether this is a detonation with an external or an internal effect. According to Violet[10] the radius of the seismically endangered zone can be calculated as follows in case of detonations with internal effects:

$$r = 1{,}54 \sqrt{q^{3/4}} \quad \text{km} \tag{3.21}$$

Here it was assumed that above-ground structures can withstand an acceleration of up to 0.1 g without damage. The error in Formula 3.21 can be $\pm$200-300 percent. Because the values for the acceleration and the shift along the earth's surface in comparison to those in the ground are increased roughly double, the effects on installations built into the ground are less than on above-ground installations at the same distances. Some values are compiled in Table 3.5 to illustrate the quake-like effects of underground detonations.

Table 3.5. Quakes Appearing along the Earth's Surface after Underground Detonation, q = 10 kt[11]

Distance km	Maximum acceleration g	Quake intensity[12]	Seismic effects
1.6	0.34	8	Slight damage to buildings with special construction; heavy destruction of standard buildings
8	0.014	4	Window panes will rattle; Damage to objects in motion; Quake is felt by many people in closed rooms, only partly by persons out in the open
16	0.003	3	People in closed rooms perceive quake-like roar of passing train
34	0.0015	1 ... 3	Sensitive individuals note vibrations [oscillations]

Review Questions

3.16. What basic effects can blast waves spreading in the ground have on terrain, buildings, and installations?

3.17. Estimate whether seismic waves spreading in the ground can be used to recognize and locate underground detonations even without special aids.

3.4. Blast Wave Propagation in Water

It follows from the elementary description of water and underwater detonations in Section 2.2.2.4. that maritime nuclear weapon detonations differ fundamentally from those in other areas both in terms of their external phenomena and in terms of the effect of the individual annihilation factors.

One of these peculiarities is the propagation of a part of the detonation energy in water.[13]

This is why in water and underwater detonations we can basically observe three forms of pressure propagation: The air pressure wave, the water pressure wave, and the surface waves.

Because we already covered the formation of surface waves, we are including here, for illustration purposes, merely one table (3.16) which shows the wave heights developing after water detonations.

Table 3.6. Some Guidance Values on the Wave Height after Water Detonation (Contact Detonations) as a Function of the Detonation Intensity

6 Detonations-stärke kt	7 Entfernung vom Nullpunkt/km 1	2	3	4	5
8	Wellenhöhe/m				
1	0,5	0,2	0,15	–	–
10	2,4	1,2	0,8	0,6	0,5
100	5,2	2,5	1,7	1,3	1,0
1000	–	5,6	3,8	2,8	2,2

Key: 6--Detonation intensity; 7--Distance from ground zero (km); 8--Wave heights, m.

In case of underwater detonations at shallow and medium depths, the wave heights can be considerably above the figures given. The energy shares for the air pressure wave, the water pressure wave, and the surface waves are determined not only by the detonation intensity and the detonation depths, but are also critically influenced by the existing water depth.

Test results on maritime detonations which have become known so far permit the conclusion that the air pressure wave is the decisive annihilation factor for surface vessels after water detonations and that even in case of underwater detonations at shallow depths the water pressure wave only slightly increases the annihilating effects of the air pressure wave. The situation is different in the case of underwater objects. Here the blast wave spreading in the water has a more or less strong effect.

The water pressure wave differs considerably from the air pressure wave:

Because the density of the water is about 800 times greater than that of air, the detonation energy (pressure energy) is passed on faster and with less loss. While, for example, the air blast wave deriving from a 20-kt detonation will cover the first 3 km in about 8 sec, the water pressure wave will cover the same distance in approximately 2 sec.

The overpressure in the water pressure wave front drops as the distance from the detonation center increases considerably more slowly than in the air blast wave front.

After a 1-kt underwater detonation at great depth, 600 m away from the detonation center, it is still about 24 kp cm^{-2}, compared to about 0.2 kp cm^{-2} along the air blast wave front following a ground burst of equivalent intensity.

The action time of the water pressure wave is considerably shorter than that of the air blast wave. It is on the order of magnitude of several hundredths of a second, in contrast to about 1 sec in the case of the air blast wave.

To understand the annihilating effects of the water pressure wave on surface and underwater vessels, it is particularly necessary to take a somewhat closer look at the reflection phenomena along the phase boundaries between water and air and water and ground (Figure 3.18)

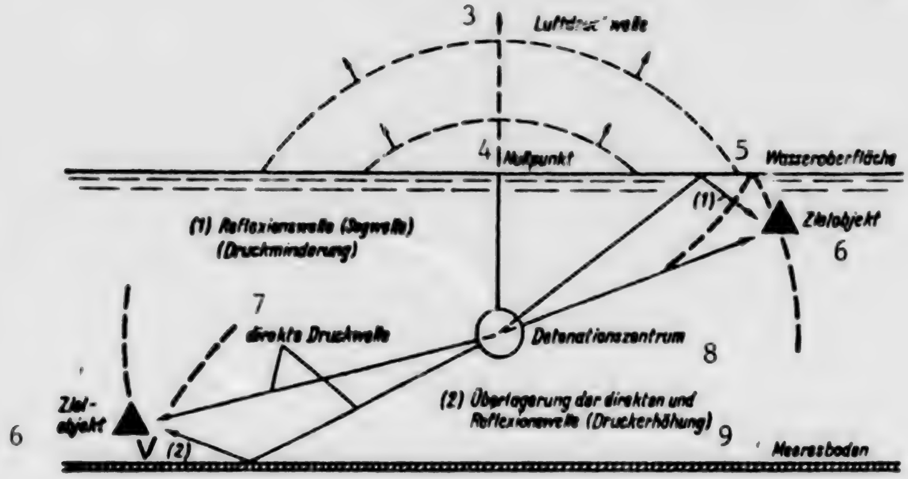


Figure 3.18. Greatly simplified illustration of propagation of water pressure wave and its reflection along phase boundaries. Key: (1) Reflection wave (suction wave) (pressure drop); (2) Superposition of direct and reflection wave (pressure rise); 3--Air blast wave; 4--Ground zero; 5--Water surface; 6--Target; 7--Direct blast wave; 8--Detonation center; 9--Ocean bottom.

In case of undisturbed propagation in open water, the water pressure wave will spread uniformly in all directions. The orders of magnitude of the maximum overpressure appearing in the water pressure wave front at the particular distances can be taken from Table 3.7 for a detonation intensity of 1 kt and with the help of the blast wave's similarity law they can be converted for other equivalents according to the relationship 3.12.

Table 3.7. Maximum Overpressure in Water Pressure Wave after 1-kt Test Detonation at 20 m Depth

1 Entfernung vom Detonationszentrum/m	200	300	400	500	600	700	800	900	1000
Δp_1/kp cm^{-2}	160	80	50	35	25	20	15	10	8

Key: 1--Distance from detonation center, m.

In case of shallow water depths or correspondingly great detonation depths, the reflection of the water pressure wave along the ocean bottom may be significant as a function of the detonation intensity.

As in the case of air bursts producing an air blast wave along the ground surface, the water pressure wave, spreading directly from the detonation center, is turned into a reflection wave on reaching the ocean bottom. The superposition of the fronts of the reflection wave, which is also possible here, and the superposition of the directly spreading wave to form the common front of the "main pressure wave" will lead to a corresponding pressure rise in the particular water layers.

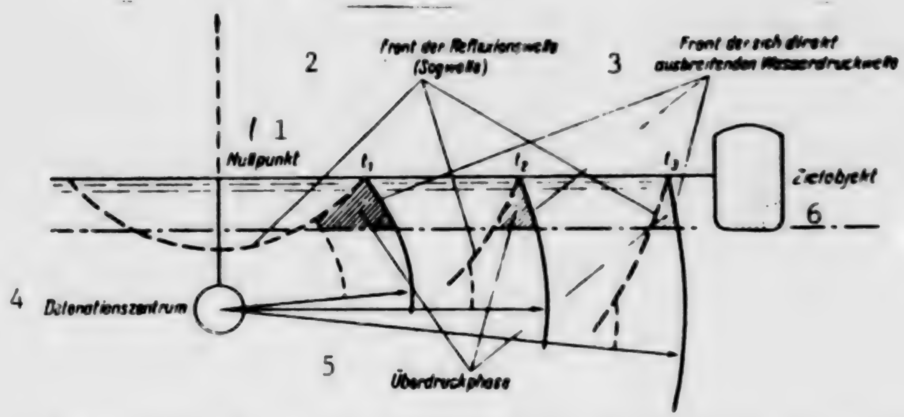


Figure 3.19. Reflection of water pressure wave along water surface. Key: 1--Ground zero; 2--Front of reflection wave (suction wave); 3--Front of directly spreading water pressure wave; 4--Detonation center; 5--Overpressure phase; 6--Target.

The reflection takes place in an entirely different fashion if the front of the water pressure wave reaches the water surface (Figure 3.19). Here the reflection wave spreads from the water surface downward and to the sides in the form of a suction wave. It follows the direct water pressure wave whereby the time differential between the moment both wave fronts become effective will depend primarily on the detonation depth and the position and distance of the particular place observed with respect to the center of the detonation. Phenomena in the water layer near the surface are of special interest here.

Because the reflection wave front here runs directly behind the direct water pressure wave front and because the superposition of both waves increases with growing distance from ground zero in terms of depth, the reflection wave will "cut off" an ever larger piece of the overpressure phase. This is why we can observe that the water pressure wave at greater distances from ground zero will in fact for the most part come to an end on reaching the open water surface.

The pressure conditions resulting in the course of this process are illustrated in Figure 3.20. As the distance from ground zero increases, the action time τ_+ of the overpressure phase decreases more and more and near the water surface moves toward zero.

In conclusion we might observe regarding these elementary comments that the values available for maritime detonations presently do not yet permit an exact mathematical-physical treatment of an entire series of parameters.

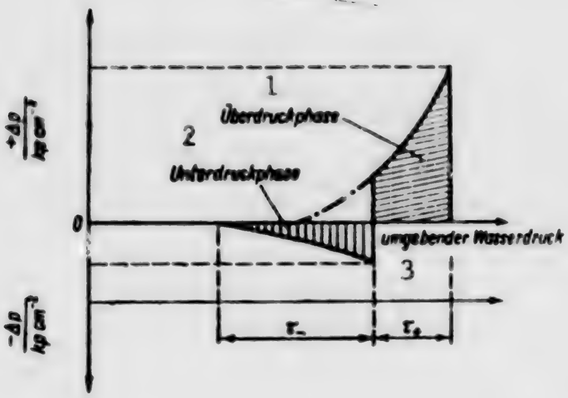


Figure 3.20. Pressure curve during process of water pressure reflection along open water surface. Key: 1--Overpressure phase; 2--Underpressure phase; 3--Surrounding water pressure.

Review Questions

3.18. By what essential characteristics does the water pressure wave differ from the air blast wave?

3.19. What is the significance of the fact that the reflection wave, developing along the open water surface after underwater detonations, is a suction wave?

3.20. In connection with the presentation in Section 2.2.2.4, explain the possible effects of the blast wave after water and underwater detonations on surface and underwater objects.

3.5. Annihilating Effects of Blast Wave and Defense against Them

3.5.1. Effect on Man and Defense Possibilities

3.5.1.1. Ways in Which Energy, Released during Nuclear Weapon Detonations, Acts on Human Organism

The injuries to human beings occurring after a nuclear weapon detonation in the immediate area around the detonation are determined primarily by their "combined" character. Because of the possible simultaneous action of pressure, light, or heat and radioactivity, we get a widely differentiated and manifold picture of injuries and damage.

The scope, type, and degree of possible injuries to man depend on the specific conditions of each detonation.

Here one must among other things consider as most important factors the detonation intensity, the type of detonation, the nature of the detonation area, the character of the particular place or the shelter situation at the moment and after the detonation as well as the meteorological conditions.

The evaluation of the blast wave and light radiation is of first-ranking significance in estimating the overall effects of a nuclear weapon detonation in the immediate detonation area.

Specifically, we must figure on the following possible damage to the human organism after a nuclear weapon detonation:

Blast and shock effect (blast wave);

Damage due to direct (immediate) effect of blast wave on organism;

Damage due to indirect effect of blast wave;

Light and heat effect (light radiation);

Primary [first-degree] burns;

Secondary [second-degree] burns;

Blinding;

Heat stroke;

Effects of nuclear radiation (instantaneous and residual nuclear radiation);

Radiation sickness after exposure to high radiation doses;

Radiation sickness due to incorporation of radioactive detonation products.

Because of the large number of factors which can influence the magnitude of the annihilating effect of a nuclear weapon detonation in the specific case, it is very difficult to come up with firm statistics on the distribution of possible damage.

For Hiroshima and Nagasaki the causes of damage were traced back to the extent of 50 percent to the direct and indirect effect of the blast wave, to the extent of 40 percent to light and heat radiation, and to the extent of 10 percent to nuclear radiation.

We can see that the scope of combined injuries is not covered here. Naturally, it is impossible to use these statistical figures as basis for field conditions without any further processing.

Under field conditions, the character and composition of the particular object, which is the target of a nuclear strike, play a decisive role.

There will thus be very great differences for example both regarding the scope and regarding the character of damage in a tank unit and in a motorized rifle unit. In case of a strike against concentrated forces, the effects will be different from those on troops quartered in a decentralized pattern.

On top of that we have the fact that the scope of indirect damage as a function of the nature of the particular detonation area is very difficult to pin down. In case of clear weather, the share of those damaged only by light radiation will be relatively large whereas during rain or fog, this type of

damage will be less significant. Similar considerations can also be entertained from other viewpoints. This is why one can consider the numbers given in Table 3.8 only as very rough approximation values.

Table 3.8. Guidance Values for the Share of Possible Damage to Troops Out in the Open (Air Burst, Heavily Built-Up or Covered Terrain)

Type of damage	Percentage share
Combined injuries	50
Traumatic injuries	20
Injuries due to light radiation	20
Radiation damage	10

The viewpoints mentioned in connection with the explanation of Table 3.8 can also be applied in judging the possible seriousness of injuries. If we refer to the zone, in which troops are reliably disabled for further combat operations after a nuclear strike, as the "annihilation zone," then one may assume that about 30 percent of the human beings will be killed directly by the detonation, that 30 percent will suffer very serious and serious injuries, and that 40 percent will come off with medium injuries while a small percentage will suffer slight injuries. A large proportion of the very heavily injured will die of their injuries after the detonation.

This annihilation zone, which is often used in tactical situation estimates, does not rule out the fact that casualties can also appear outside this area. In general one may assume that the effects of a nuclear weapon detonation can extend up to 1.7 times the radius or up to 3 times the surface of the annihilation zone; but here most of the damage will involve slight injuries. This region is referred to as the "neutralization zone."

3.5.1.2. Effect of Blast Wave on Unprotected Individuals

The blast wave from a nuclear weapon detonation takes effect due to the sudden pressure rise as the blast wave front reaches a terrain sector (blast effect) and the fast movement speed of the air masses (shock effect) in this front with respect to unprotected persons. The resultant injuries are called direct or indirect blast wave damage.

The degree of the damaging effect of the blast wave is determined primarily by the magnitude of the overpressure values appearing at the particular distances and the blast wave's action time. In case of standing individuals, the movement speed of the air masses along the wave front also exerts the kind of influence which cannot be overlooked. In the range of detonation intensities we are interested in here, the dependence of the annihilating or damaging effect of the blast wave on the action time however is not so great that it would have to be investigated further below. This is why Table 3.9 gives the degree of anticipated blast wave damage only as a function of the overpressure.

Table 3.9. Guidance Values for Damage to Unprotected Persons at Certain Overpressure Values

Overpressure along wave front kp cm^{-2}	Degree of injuries
0.2-0.3	Slight injuries
0.3-0.6	Medium injuries
0.6-1.0	Severe injuries
> 1	Extremely severe or lethal injuries

The classification of injuries is difficult. We might give some examples for illustration purposes. Among light injuries we can include contusions, sprains, abrasions, etc. Medium injuries for example are severe contusions, large bursting wounds, and bone fractures. Serious injuries include damage to the internal organs, tearing of the tympanic membrane, and others.

In general, we can expect the following damage due to the direct action of the blast wave:

Tympanic membrane tearing, possibly also damage to the auditory organ;

Tearing of pulmonary alveoli (bubble formation) or tearing of vessels in the lungs (lung hemorrhages and entry of air into the vessels, air embolism);

Tearing of abdominal organs, appearance of spleen and liver tears (internal injuries);

Cardiac shock with irregular heart activity;

Removal of skin.

Indirect blast damage results from the fact that the individual is either hit by objects which are lighter than he and which in part can have the effect of a projectile causing deadly wounds or that the individual himself is flung away by the blast wave and thus suffers fractures, bruises, bursting wounds, etc.

One must furthermore consider possible damage due to the destruction of vehicles, collapsing shelters, collapsed trenches, collapsing houses, falling trees, etc.

It is obvious that the nature of the detonation area will very greatly influence the character of these injuries.

This is why one must keep in mind that the effects of the blast wave on the troops cannot be simply calculated with the help of the schematic use of the values given in Table 3.9. That applies particularly to operations in cities, villages, or woods. In towns, for example, people outside cover can suffer serious and even deadly injuries at overpressure values of 0.2 or 0.3 kp cm^{-2} due to collapsing buildings and flying wreckage. Because window panes can be broken already at an overpressure of 0.02-0.05 kt cm^{-2}, the glass

splinters, accelerated by the blast wave, even at such distances, which by far exceed the immediate detonation area, constitute an extraordinary threat and can cause cuts and eye injuries.

Similar considerations result as far as woods are concerned. They of course, as we said before, can to a certain degree weaken the effect of the blast wave but on the other hand they can also cause voluminous indirect damage. It must be emphasized here again that, at overpressure values of 0.3-0.5 kp cm^{-2} trees will knocked down, branches are torn off, etc. These effects naturally depend on the type of the forest, the season, the weather conditions, and other factors.

On top of that we have the possible start of vast forest fires and tree barriers which will not only considerably encumber the movement of troops after nuclear weapon detonations but which can also be the cause of secondary losses. This is why one must under no circumstances overestimate the possible protective character of a forest. More detailed information on this point can be found during the investigation of the effects of the blast wave and the light radiation on woods.

Summarizing we can say, regarding this problem complex, that the estimate of the possible effects of the blast wave deriving from a nuclear weapon detonation, in addition to the calculation of the effective overpressure values, also presupposes a detailed evaluation of the detonation area and thus of the indirect pressure damage. In cities and forests, indirect pressure effects can by far exceed the direct pressure effects.

Table 3.10 contains some numerical data on the damaging effect of the blast wave on human beings outside cover. Indirect injuries due to the nature of the detonation area are not considered here.

Table 3.10. Guidance Values on the Gradual Damage to Human Beings Outside Cover due to Blast Wave from Air Bursts

1 Detonationsstärke kt	2 Grad der Verletzung 3 tödlich	4 schwer	5 mittel	6 leicht
	7 Entfernung vom Nullpunkt/m			
1	200	250	270	300
10	500	600	650	700
100	1400	1600	1700	,900
1000	3000	3400	3600	3900
10000	6600	7300	7700	8400

Key: 1--Detonation intensity; 2--Degree of injury; 3--Deadly; 4--Serious; 5--Medium; 6--Light; 7--Distance from ground zero, m.

After ground bursts, the injury radii are somewhat smaller than would be indicated in the table. The differences amount to a maximum of 25 percent. The values pertain to prone individuals. In standing individuals, the particular injury radii are considerably bigger (in the megaton range by more than 100 percent).

Between the first flash of lightning from a nuclear weapon detonation and the approach of the air blast wave front at such distances, where we must still expect the blast wave to cause injuries, there is a time differential ranging between several seconds and several tens of seconds. Regardless of that however light radiation and instantaneous nuclear radiation take effect immediately.

This is why persons, who are outside shelters, must immediately seek cover and hug the ground the moment they detect a nuclear weapon detonation. The arms must be used to shield the face. A maximum increase in the shelter condition here presupposes that even the slightest protective properties offered by the terrain must be fully exploited. Leaving cover or standing up is possible only after the blast wave has passed the area.

In open, level terrain, the best position is with the feet toward ground zero. In this case, for example, the tympanic membrance is torn only at an overpressure of 1 kp cm^{-2} whereas this happens already at 0.35 kp cm^{-2} when the head is at a right angle to the direction of propagation of the blast wave front.

If there are any rises, undulations, tree stumps, wall remnants, roadside ditches, etc., in the area, then the head should be moved as close to the particular cover while the body must be kept flat.

What we have said so far shows that the level of possible casualties among the troops due to a blast wave and due to a nuclear weapon detonation as a whole is decisively influenced by the training level. Correct action by each fighting man on the battlefield, constant readiness to exploit all protective possibilities in the particular situation, and short response times are indispensable requirements to preserve combat strength and thus to accomplish the combat mission.

3.5.1.3. Special Aspects of Effect on Individuals under Cover

In addition to utilizing natural cover provided by the terrain (hollows, depressions, gorges, valleys) and individual elements in built-up areas and vegetation cover to provide protection against the annihilating effects of the blast wave or a nuclear weapon detonation as a whole, the construction of field fortifications, especially shelters (shallow individual scooped-out rifle pits, foxholes, trenches, shelters) is of great significance. They decisively reduce the annihilation radii of the blast wave and the other annihilation factors and offer reliable protection even at distances at which unprotected persons would suffer deadly wounds.

Beyond that, combat vehicles--especially armored vehicles (tanks, SP mounts, APC's, and armored special vehicles) offer a degree of protection although it does vary. This degree of protection has gone up constantly in recent years and will continue to go up with the help of suitable design and other measures, for example, special protective facilities, hermetic sealing of combat compartments.

Table 3.11 is a comparison of the various annihilation zones for individuals to illustrate the protective properties of various installations or vehicles.

Table 3.11. Radii of Annihilation Zones after Air Bursts for Persons as a Function of the Shelter Condition

1 Detonations-stärke	Schutzzustand des Menschen 2			
	3 außerhalb von Deckungen	4 in Deckungsgräben	5 in mittleren Panzern	6 in Unterständen leichten Typs
kt	7 Entfernung vom Nullpunkt/m			
1	800	500	400	200
10	1500	900	800	300
100	3000	1800	1500	600
1000	6000	4000	2900	1300
10000	13000	8600	6400	2800

Key: 1--Detonation intensity; 2--Individual's shelter condition; 3--Outside cover; 4--In trenches; 5--In medium tanks; 6--In lightly-built shelters; 7--Distance from ground zero, m.

In interpreting the values in the table one must keep in mind that every shelter facility must perform two functions to prevent or reduce the annihilating effect of the blast wave deriving from a nuclear weapon detonation: First of all, protection against the blast and shock effects and, besides, protection against indirect injuries due to rubble.

Both viewpoints must always be equally considered in the quartering and movement of troops for the sake of protection against nuclear weapons.

Regardless of that, the blast wave of course also up to certain distances from ground zero will destroy shelters of all kinds or will damage them and can thus inflict injuries on persons in them. The character and degree of these injuries will depend on the destruction or damage pattern in the particular installation.

When putting troops in foxholes, trenches, and shelters there is the danger that these facilities might be crushed or severely shaken. This means that traumatic, that is to say, mechanical damage will prevail under these conditions. Complete destruction of the particular shelters can also lead to the annihilation of the people in them. In such shelter facilities, which are only slightly damaged, one must also figure on light injuries to individuals whereby combat strength can certainly be maintained if only the entrances, the ceilings, etc., are damaged.

But it is not possible in every case to draw conclusions as to injuries to people in certain shelters in the light of the external destruction of that installation. For example, in case of ground and underground bursts, the system of field fortifications can be heavily shaken in the immediate

detonation area. Due to the seismic effects of the ground pressure wave, individuals can suffer serious injuries even in those facilities which hardly reveal any noteworthy damage on the outside. These phenomena appear especially in concrete buildings which are heavily shaken by the blast and shock in the ground at relatively great distances but which are hardly destroyed.

In this connection it is necessary to make some remarks on the degree of protection offered by trenches. The protective properties of a trench among things depends heavily on its position with respect to the blast wave front's propagation direction. If the ditch runs laterally to it, the movement speed air along the trench bottom can be reduced to as much as 50 percent of the standard value. But if there is no cover on the trench, there will be a corresponding increase in the dynamic pressure and thus in the injuring effect. This is why the protective action of a shelter trench consists less in the reduction of the direct effects of the blast wave and more in the reduction of the indirect effects.

The blast wave has a far lesser effect on crews in armored vehicles than on personnel out in the open. If the hatches are closed, the overpressure at the particular distances in a tank will be reduced to 30-50 percent and in amphibious tanks to 10-15 percent. Similar values can be achieved in fully hermetic combat compartments. As a result of this, the particular injury radii are heavily reduced.

In looking at these questions one must however strictly distinguish, for example, between the distances up to which tank crews can be knocked out and the distances up to which the tank itself can be damaged. In the case of armored vehicles it is possible that they might still be fully or partly usable after a nuclear weapon detonation while the crews might be seriously wounded.

3.5.2. Effects on Terrain, Buildings, and Woods--Conclusions for Unit Operations

3.5.2.1. Effects of Blast Wave in Towns

Nuclear weapon detonations cause particularly heavy destruction in cities or heavily populated regions. This produces not only casualties among the civilian population and the troops quartered in these areas but also causes considerable effects on the conduct of operations in these regions.

Residential buildings, factories, etc., offer little resistance to the blast wave from a nuclear weapon detonation because they are not designed for any great overload. Buildings erected in the steel skeleton style or with large-size panels constitute an exception here.

In contrast to the annihilating effect of bombardments, such as they are sufficiently well-known from World War II, a nuclear weapon detonation will cause destruction on a more or less large and continuous surface area.

The total size and the type of destruction and damage will depend on very many factors. The most important ones are the detonation intensity, the distance from the detonation site, the type of detonation, the strength [hardness] and dimensions of the buildings and installations, the density of the buildup pattern, and the terrain relief.

It is therefore not simply possible to transpose the annihilation yardsticks of American nuclear bombs dropped on the Japanese cities of Hiroshima and Nagasaki to Europe conditions because the number of buildings consisting of wood and light parts in both cities was great and because there was only a very small number of European-style buildings. This is why the effects of light radiation in comparison to the blast wave are too great for European conditions.

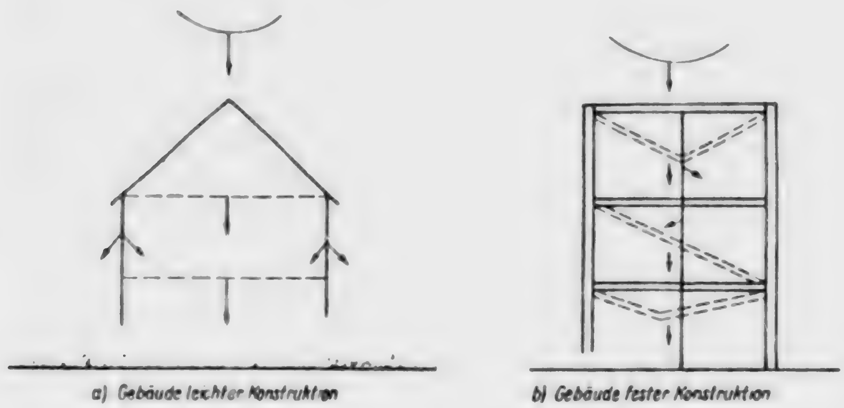


Figure 3.21. Vertical pressure stress on buildings in the area of ground zero after air burst. (a) Building with light construction; (b) Building with solid construction.

The way in which the blast wave acts on buildings and installations differs in the near zone and in the far zone. Here one must particularly consider the position of the buildings with respect to the front of the spreading blast wave. Because the destruction character depends on very many characters, we can explain only a few basic viewpoints here.

In the near zone, especially in the area around ground zero, after an air burst, the blast wave acts upon the buildings and installations in a more or less perpendicular fashion. This is why the horizontal elements are exposed to particularly heavy pressure stress. As a result of this, weak buildings will collapse completely whereas in the case of strong building structures it will be primarily the roofs and the in-between ceilings that will be crushed while the side walls will reveal relatively little damage.

At greater distances from ground zero both the horizontal and the vertical components of the blast wave will have their effect while in the far zone the destruction pattern will increasingly be determined by the horizontal component of the blast wave so that it will be especially the walls that will be exposed to heavy pressure stresses. Once the blast wave front reaches

a terrain complex, the sudden braking and the subsequent reflection will cause a severe pressure rise. Because of the tremendous speed of blast wave propagation, the blast wave itself will very quickly also flow around big buildings, to the site and also in terms of height and it will then have an all-around effect also on the side and rear walls as well as on the roof.

In buildings with many windows or comparatively weak outside walls, which offer little resistance to the penetration of the blast wave, one can observe phenomena representing an explosion as the blast wave front reaches the buildings.

Because of the fast penetration of the blast wave into the buildings, practically the full side pressure will have its effect from the inside while the outside pressure on the roof is reduced by the developing suction of the overflowing blast wave. As a result of this pressure distribution, the roof is forcefully flung away upward and the house seems to explode.

Buildings into which the blast wave cannot penetrate quickly are knocked down as a function of the overpressure and their hardness by the pressure rise due to the reflection along the front side and the additional suction effect along the reverse side in the direction of the spreading blast wave front or wreckage parts are swept along.

Naturally, the examples indicated here cannot point up the large number of ways in which the blast wave can act on a building especially since the buildings are hit not only by the sudden overpressure in the blast wave front but also by the dynamic pressure from the moving air masses.

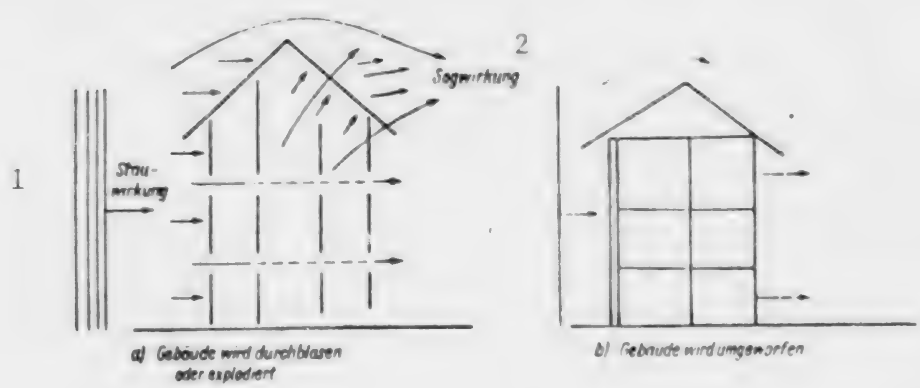


Figure 3.27. Horizontal pressure stress on buildings due to main blast wave front. Key: (a) Wave blows through building or building explodes; (b) Building is knocked down; 1--Dynamic pressure effect; 2--Suction effect.

Blast wave destruction depends not only on the magnitude of the overpressure or the dynamic pressure and the action time of the blast wave but also--as we can see from the examples given--on the building style. A building's

resistance depends on its construction and the strength [thickness] of the supporting elements, its dimensions, and, for example, also on the number of doors and windows.

Buildings made of concrete or steel-concrete or prefabricated concrete parts are most resistant; industrial, scale-like frame structures with comparatively large surfaces are weakest. Brick buildings likewise only offer little resistence to the annihilating effect of the blast wave because they have little elasticity and even minor shifts in the load-bearing walls can cause individual stories to collapse.

The shape of the buildings on the other hand plays a minor role. An exception here consists only of aerodynamically very favorably built chimneys. Table 3.12 contains some statistics on destruction pressures for buildings and installations.

The degrees of destruction are defined as follows:

Heavy destruction: Total damage; building cannot be restored.

Medium destruction: Above all, less important parts of the installation are destroyed; restoration is possible by means of general repairs.

Damage: Light structural elements, such as roofs and window glass are destroyed.

Electric power plants, gas works, high-voltage installations, etc., are also destroyed as a result of a nuclear weapon detonation. This first of all knocks out the energy supply system or paralyzes it partly; besides, there can be secondary fires due to short-circuits or escaping gas.

The water supply after the detonation is no longer guaranteed in many places due to the destruction of water works, distribution systems, pipelines, etc.; this can have a severe effect on fire-fighting. Because of the destruction of the communications network and the failure of power supply there can be major difficulties in preparing a situation estimate on the area of destruction.

The destruction of or damage to streets, bridges, railroad installations, and various traffic systems will make it extremely difficult to penetrate into the detonation area and will delay measures to eliminate the consequences. The effects resulting from all of this on the conduct of march movements or also on subsequent combat operations can be extraordinarily complicated.

Table 3.12. Guidance Values for Destruction Pressures on Various Building Types and Installations

1 Art der Gebäude und Anlagen	2 Zerstörungsgrad		
	3 schwer	4 mittel	5 Beschädigung
	6 Überdruck/kp cm^{-2}		
7 Industriegebäude mit Metall- oder Stahlbetonskelett	0,5 ··· 0,8	0,3 ··· 0,5	0,05 ··· 0,2
8 Steinhäuser mit mehr als 3 Stockwerken	0,3 ··· 0,4	0,1 ··· 0,2	0,03 ··· 0,05
9 Steinhäuser unter 3 Stockwerken	0,35 ··· 0,45	0,12 ··· 0,25	0,03 ··· 0,05
10 Holzhäuser	0,2 ··· 0,3	0,08 ··· 0,12	0,03 ··· 0,05
11 Stahl- und Stahlbetonbrücken	2 ··· 10	2 ··· 10	0,5 ··· 2
12 Holzbrücken	0,5 ··· 1	0,3 ··· 0,5	0,1 ··· 0,3
13 begehbare Kanalisationsschächte	≧ 20	15 ··· 20	6 ··· 10
14 unterirdische geschweißte Stahlrohre mit einem Durchmesser $d < 350$ mm	≧ 20	15 ··· 20	6 ··· 10
15 unterirdische Guß-, Zement- und Steingutrohre	≧ 20	10 ··· 20	2 ··· 6
16 unterirdisch verlegte Kabel	≧ 10	5 ··· 10	2 ··· 3
17 elektrische Überlandleitungen	1 ··· 2	0,5 ··· 1	0,2 ··· 0,3
18 Industrieanlagen	–	0,6 ··· 0,7	0,2 ··· 0,3
19 Kraftwerke und Umspannstationen	1	0,5	0,1 ··· 0,3

Key: 1--Type of building and installation; 2--Degree of destruction; 3--Heavy; 4--Medium; 5--Damage; 6--Overpressure, kp cm^{-2}; 7--Industrial building with metal or steel-concrete skeleton; 8--Stone houses with more than three stories; 9--Stone houses with less than three stories; 10--Wooden houses; 11--Steel and steel-concrete bridges; 12--Wooden bridges; 13--Passable sewer shafts; 14--Underground welded steel pipe with diameter $d < 350$ mm; 15--Underground cast-iron, cement, and stone pipes; 16--Cable laid underground; 17--Electrical overhead line [power lines]; 18--Industrial installations; 19--Power plants and transformer stations.

In this connection it is necessary to add some statements on the rubble problem and the resultant blocking of streets.

In Hiroshima and Nagasaki, rubble constituted a serious obstacle to rescue and recovery activities. This question would be even more problematical under European conditions.

In both Japanese cities, firefighting equipment was almost completely blocked by collapsing buildings and thus could not be used. The few still usable vehicles had a difficult time reaching the sources of fire.

Only about 10 percent out of the total volume of standard residential buildings are combustible. This is considerably less than in Hiroshima and Nagasaki in 1945. This circumstance of course would have an unfavorable effect on the development of fire foci but on the other hand it would cause the streets to be blocked even more than in Japan. (This observation springs from the fact that buildings erected according to modern technologies are presently not yet typical when it comes to an overall estimate pertaining to cities.)

If one takes a more thorough look at the question of street blocking, one finds that the density of the buildup pattern and the total layout of a city in particular are the most important factors. Here one must judge the distances from ground zero, the width of the streets, their pattern with respect to the direction of propagation of the blast wave front, as well as the building style and the height of the adjoining houses.

More detailed data can be found on this point among other things in Tsivilyev[15]. Accordingly, the rubble fields, formed after the destruction of buildings due to a nuclear weapon detonation, consist of a chaotic pileup of larger and smaller chunks of walls, ceilings, partition walls, furniture, etc.

In case of complete destruction of residential buildings and industrial buildings, we get an average of 350-500 m^3 or 50-200 m^3 rubble for every 1,000 m^3 of initial substance. The share of cavities within the rubble fields is assumed to be 30-40 percent for stone buildings and 40-50 percent for buildings made of prefabricated concrete parts.

The weight of the rubble on the average fluctuates between 1.5 and 1.7 Mp m^{-3}. Table 3.13 presents some numerical values on the structure and percentage makeup of rubble.

Table 3.13. Guidance Values for Rubble Formation Following Destruction of Various Building Types by Blast Wave from Nuclear Weapon Detonation[16]

Rubble composition	Percentage share of rubble chunks in the destruction of			
	Stone structures		Miscellaneous structures	
	Industrial buildings	Residential buildings	Wooden houses	Large-block design
Wall chunks from burst brick walls up to 1 m^3	20	40	13	-
Steel-concrete and concrete chunks up to 0.8 m^3	60	10	-	75
Wooden structures	3	30	75	2
Metal structures including equipment	10	5	2	18
Rubble waste	7	15	10	5

Individual independent or also continuing rubble fields and zones can form as a function of the factors mentioned.

If we have overpressure values of $\Delta p_f \geq 0{,}5\ \mathrm{kp\ cm^{-2}}$ and a built-up area density of at least 40-50 percent, the heights of the rubble fields will average between 2 and 6 m. In the direction of propagation of the blast wave, the rubble masses can be shifted up to 25 m depending upon the height of the buildings. Individual rubble pieces are transported over distances of 100 m and more by the blast wave.

As an example we can say that in cities with an average built-up area density of 30 percent and mostly five-story buildings, we will get a continuous rubble zone if the maximum overpressure is in the range of 1.3-1.5 kp cm^{-2}.

Regarding the blocking of streets we distinguish the following:

One-sided rubble fields (a continuing rubble-free strip remains on one side of the street);

Two-sided rubble fields (a free strip of varying width remains in the middle of the street but it is sometimes also blocked by rubble);

Continuing rubble fields. It is assumed that two-sided rubble fields are formed on the streets if their axes form an angle of less than 50° with the blast wave front's propagation direction.

A street without prior rubble removal is considered to be fully passable if there is a free strip with a width of at least 3.5 m.

Streets whose width exceeds the height of the adjoining houses will be relatively easily passable even after a nuclear weapon detonation as a function of the distance from ground zero. Streets which run radially with respect to the detonation center or ground zero will be better passable than streets running laterally with respect to the blast wave front's propagation direction.

Table 3.14 contains some numerical data on destruction and traffic obstacles in cities (see also the nomograms in Chapter 8).

Table 3.14. Guidance Values for Destruction and Traffic Obstacles after Nuclear Weapon Detonations over Cities

Detonationsstärke kt	normale Straßen unpassierbar	völlige bis schwere Zerstörungen	mittlere bis leichte Zerstörungen	Verkehrsbehinderungen für Kfz
1	300	400	800	1300
10	700	800	1800	2800
100	1400	1700	3800	6000
1000	3000	3000	8000	12000
10000	7000	8000	17000	25000

Key: 1--Detonation intensity, kt; 2--Normal streets impassable; 3--Complete to heavy destruction; 4--Medium to light destruction; 5--Traffic obstacles for motor vehicles.

In case of ground bursts, the destruction radii are about 10-20 percent smaller than after air bursts. This is due to the fact that, after a ground detonation, a part of the energy is consumed by the formation of the crater and the screening effect of hills or buildings. But here one must keep in mind that destruction in the center of the detonation is greater than after an air burst. Due to the partial propagation of the blast wave in the ground in the form of seismic waves, we can also expect heavy destruction in underground installations. This naturally reduces the protective effects of improved shelter facilities of all kinds in the immediate area around the detonation. On top of that we have high radioactivity in the detonation area which with a great degree of probability will expose unprotected persons and individuals in damaged shelters to high radiation doses and which will make practical measures to eliminate the consequences in the area around ground zero immediately after a ground burst impossible.

This is why on the whole heavier losses can be anticipated after ground bursts than after air bursts in spite of the relatively smaller blast wave destruction areas.

From what we have said so far we can draw some basic conclusions regarding military unit operations.

Big cities and industrial regions are as a rule unsuitable for quartering troops under the conditions of nuclear weapon employment. The continuous destruction zones consisting of buildings and installations, resulting from enemy nuclear strikes, can inflict heavy losses on the troops.

Freedom of movement is severely restricted by the fact that shelter facilities, vehicles, and combat equipment are buried and that march routes and trails are blocked. In addition there is the possibility of vast area fires.

Under these conditions, the measures to be taken to correct the consequences are very comprehensive and complicated. Their implementation calls for a major effort in terms of personnel and equipment.

For the reasons given and on the basis of an exact situation estimate the important thing is to estimate the scope and character of possible enemy nuclear strikes in a forward-looking fashion and to consider it to the fullest extent in planning future combat operations. The edges of cities, loosely built-up area, parks, etc., must be used for quartering troops. Suitable facilities must be improved to form shelters for troops and combat equipment with Engineer backup support. Special attention must be devoted to traffic movement by widening the streets, removing bottlenecks, reinforcing bridges, etc.

During the course of march movements, major cities and population concentration areas should be skirted to the extent possible. March movements must be accomplished with maximum possible speed and safety intervals between individual columns and vehicles must absolutely be maintained. Traffic buildups or intersections of convoy movements must absolutely be prevented in areas around highway junctions, river crossings, and passes.

Reconnaissance, street clearance, firefighting, rescue and evacuation of casualties must be considered one single task in organizing and carrying out rescue and recovery activities.

3.5.2.2. Effects of Blast Wave in Woods

Destruction of woods, windbreak, and fires resulting from nuclear weapon detonations likewise depend on very many factors.

As the most important ones here we might mention the tree cover, the density of the woods, the height of the trees, the nature of the soil, as well as the season and weather conditions.

Because woods can have a significance which in combat operations must by no means be underestimated both regarding the covered quartering of troops and the performance of maneuvers, we will present some viewpoints on the effect of the blast wave on woods below.

In Section 3.2.5.2. we already pointed out that the maximum overpressure inside a forest differs only very little from the maximum overpressure along the wave front which is spreading over the forest and that the reduction of

The action radii with respect to the open terrain therefore can be traced above all to the reduction of the movement speed of the air masses in the wave front.

Not all forests reveal the same protective properties. Besides, there are partly different viewpoints regarding the blast wave and light radiation.

In general we can say that it is primarily the density of the forest and the thickness of the tree trunks that are decisive in weakening the dynamic pressure. Young low woods will have a considerably lesser effect on the propagation of the blast wave than a high forest with correspondingly thick trunks. But here one must keep in mind that, in the first case, the trees will react more elastically to the effect of the blast wave than in the second case and that therefore the size of the windbreak and thus also the possible blocking will differ.

In the summer, deciduous woods provide better protection against nuclear weapon detonations than evergreen woods because they bring about a certain weakening both with respect to the blast wave and with respect to light radiation.

We get differing effects in evergreen forests. Pine trees are anchored with their roots only on the surface, especially in sandy and rocky soils. This is why one must expect the blast wave will easily uproot the trunks and that vast blockages will develop in pinewoods due to the wind break.

In constrast to that, fir trees are firmly anchored in the ground with their pile roots. This is why one may assume that trees in fir forests will for the most part be broken off by the blast wave. This breaking of trees and the fact that branches are torn off--fir wood is considerably more brittle than pine wood--cause a particular danger of injuries due to the "bullet" effect of accelerated wood fragments. On top of that we have the fact that the danger of fires in fir forests is great.

By way of summary we can comment regarding this question that the radii of the zone in which persons in forests are directly damaged by the blast wave are smaller than in open terrain. This protective effect however can under certain circumstances be cancelled out again by the indirect effects of a nuclear weapon detonation, that is to say, by blockages and fires.

Table 3.15. Average Values for the Effect of the Air Blast Wave on Evergreen Woods

1 Detonations-stärke kt	2 schwere Zerstörungen (unpassierbar)	3 geringe Zerstörungen (Behinderungen)	4 Straßenbäume geknickt
	Entfernung vom Nullpunkt/m 5		
1	400	800	550
10	1000	1700	1300
100	2600	4500	3200
1000	6000	11000	8000
10000	17000	30000	23000

Key: 1--Detonation intensity; 2--Heavy destruction (impassable); 3--Minor destruction (obstacles); 4--Trees along streets broken off; 5--Distance from ground zero, m.

Because light radiation in addition to the blast wave also decisively contributes to the annihilating effects of a nuclear weapon detonation on woods, the information below must be viewed in conjunction with the statements we made in section 4.3.3.2.

In stationing troops in woods, we must use those areas which are no more than several hundred meters away from the edge of the woods. Only under this condition is it possible relatively quickly to leave the endangered areas when wind break zones and area fires develop.

The particular forest region must have an adequate network of roads, trails, and clearings and must permit the concealed parking of combat vehicles in convoy formation.

After the vehicles have been moved off the roads, the vehicles must face forward, toward the road, in the direction of movement, so that the reassembly of the convoy will not turn into a time-consuming maneuver. Each column must be assigned separate "exits." In case of mixed convoys, we should try to put "strong" vehicles at the head of the column. Shelters are to be built for the personnel as in open terrain. The organization and implementation of fire protection measures assume great significance.

3.5.3. Effect on Field Fortifications and Barriers

Because of the large number of different objects and effects deriving from a nuclear weapon detonation, we will consider only some general viewpoints here in terms of major categories.[17] Concerning field fortifications, the blast wave represents the main annihilation factor deriving from a nuclear weapon detonation. In addition to the immediate destructive effect of the blast wave on the various objects and installations, its possible terrain-altering influence also plays a role which should by no means be underestimated.

The volume and character of destruction will depend on the detonation intensity, the detonation type, the distance from ground zero, the hardness of the installations, as well as the nature of the terrain itself.

In describing the destructive effects of the blast wave on field fortification, it is customary to speak of complete, medium, and light destruction.

We speak of complete destruction if the particular installation was so heavily hit as a result of a detonation that its intended function can no longer be restored.

In case of medium destruction, the adjoining trench portions, entries, rifle ports, etc., can be completely destroyed whereas the walls, ceilings, or supporting elements themselves were only deformed to such an extent that the installation as a whole remains preserved and that the interior was not buried under earth. This definition shows that, in case of medium destruction of an installation, we must figure on considerable losses among the personnel.

Light destruction includes damage such as the deformation of linings, insignificant shifts of load-supporting elements, the appearance of cracks, the loosening of anchoring devices, etc. In all of these cases however the object remains operational.

Because field fortifications are above-ground objects which are more or less built into the ground or which can also be underground, it is possible that, as a function of the detonation type, both the air blast wave and the ground pressure waves or seismic waves propagated in the soil can lead to destruction. From this angle it is not only the terrain relief that is of interest but also the geological structure in the detonation area. One may thus for example expect that trenches, which are in sandy soil, will be crushed or will collapse over considerably greater distances than those in solid ground. Deep-situated Engineer works can be flooded as a result of shifts in the soil and cracks when the water table is high. Similar aspects are possible after detonations in lake regions, near rivers, ponds, etc., when dams break, when masses of water are accumulated, etc. All of these aspects, which can be supplemented with the help of additional examples, mean that an exact evaluation of the effects of a specific nuclear weapon detonation is connected with considerable difficulties.

We might give the following statistics to describe the possible orders of magnitude of destruction. In the case of ditches which are not fully lined, an overpressure of 0.4-0.8 kp/cm^{-2} will already lead to medium destruction. In fully improved trenches, this happens only at between 0.8 and 1.6 kp/cm^{-2}. Similar overpressure values lead to medium destruction of underbreastworks. Depending on their hardness, shelters will suffer medium destruction in case of overpressure values of 2-10 kp/cm^{-2}.

In addition to the direct destruction of defense works, the blast wave also acts upon wire barriers, minefields, etc. This can cause lanes to develop in barrier systems which the enemy will seek to exploit. In case of barbed wire entanglements mounted on rows of posts, an overpressure of 0.2-0.4 kp/cm^{-2} will already lead to medium destruction, that is to say, the destruction

of individual posts, the deformation of the frames, and the partial breakage of the wire. In the case of trip-wire barriers, the overpressure values required for corresponding damage will have to be twice as high.

In the case of AT and anti-personnel mines, the load pressures, causing them to be triggered by the blast wave from a nuclear weapon detonation, depend greatly on the construction. Here one must keep in mind that it has been possible to develop mine types which are relatively resistant to the blast wave. This applies particularly to AT mines. Corresponding statistical data can be found in pertinent service regulations.

3.5.4. Effect on Combat Vehicles and Technical Combat Equipment

In the case of technical combat equipment and vehicles the blast wave likewise represents the main annihilation factor although light radiation to a certain degree contributes to the overall destruction pattern. Due to the large number of various technical combat equipment items issued to the troops as well as the large number of vehicles and their very widely differentiated resistance properties against the blast wave it is naturally impossible to come up with a general statement regarding the destructive effects of a nuclear weapon detonation. But we can establish basically that the equipment and gear as a rule will likewise remain operational at ranges within which the troops themselves retain their combat strength. Exceptions among other things exist with a view to such sensitive instruments and systems as radar stations, radio sets, and aircraft where the destructive pressures, when these stations and equipment items are out in the open, are partly below the pressure values at which human beings suffer serious injury.

This kind of estimate however presupposes by way of restriction that the nature of the particular detonation area be subjected to a critical evaluation and that the placement of technical combat equipment and vehicles likewise be analyzed.

The maximum reduction in the destruction radii for combat vehicles and technical combat equipment as well as supply items in addition to their decentralized placement will presuppose the following:

Exploitation of natural protective properties offered by the terrain;

Improvement of open and covered shelter pits by the Engineers;

Prevention of secondary effects of nuclear weapon detonation on these equipment items.

As we stated in detail already in Section 3.5.1 regarding the destructive effects of the blast wave on man, destruction, in the case of technical combat equipment and vehicles, likewise is confined not only to the direct effect of the blast wave but also includes direct blast wave damage. It is quite understandable that manifold destruction or damage to equipment is possible in towns due to collapsing buildings or in woods due to broken or uprooted trees. In these cases, the corresponding destruction zones will differ greatly from those in level, open terrain.

On top of this we have the fact that, for example, APC's and tanks, which were in covered positions at the moment of detonation, as a function of the character of these covered positions will be partly or completely buried or blocked due to the destruction of these positions and that--although they may remain undamaged--they will for a certain period of time lose their mobility or maneuverability.

In case of armored vehicles, which because of their construction are extraordinarily resistant to the blast wave, dirt, stones, dust, etc., which are forced into the combat compartment or the gun barrel or the MG barrel by the blast wave, can make it impossible immediately to open fire after a nuclear strike or can delay the opening of fire.

Because of the varying composition of the objects, which can be the target of a nuclear strike, the evaluation of the anticipated effects from a nuclear weapon detonation above all presupposes orientation toward elements with little resistance. For example, trucks or unarmored prime movers are generally considerably more sensitive to the blast wave than most of the tube artillery systems. One result of this can be that the guns at equal ranges retain their operability while prime movers will suffer serious damage. In the case of tanks we must include the breakage of antennas among light damage because the tank and its crew after all may remain combat-ready; nevertheless, this naturally has a severe effect on command in combat. We can find additional examples for this problem complex and all of them boil down to the fact that we must critically evaluate the annihilation radii or destruction zones determined as a result of estimated computations and that one must not overestimate their information content. Here again it is true that one cannot get an exact and detailed overview of the situation arising after a nuclear weapon detonation only on the basis of advance calculations.[18]

Review Questions

3.21. Explain the term "combined damage" to persons after nuclear weapon detonations. Under what situational conditions can one expect them with a great degree of probability?

3.22. Describe the different effects of the maximum overpressure in the blast wave front and the fast speed of the moving masses in the air blast wave upon the troops.

3.23. What basic requirements must be established for the troop assembly areas in order to minimize indirect blast wave injuries?

3.24. How must the fighting man behave at the moment of perception of a nuclear weapon detonation in the terrain?

3.25. In conjunction with Figure 3.13, explain the protective properties offered by a trench. Why is the construction of shelter trenches extraordinarily important?

3.26. What is behind the requirement for the constant exploitation of natural protective properties offered by the terrain?

3.27. Explain the character of destruction and blockages resulting from the blast wave in towns. What basic pertinent differences can one detect in the near and far zones?

3.28. What additional nuclear defense measures for military units must be organized and carried out during combat in cities?

3.29. What are the factors that determine or influence the passability of roads after nuclear weapon detonations?

3.30. Outline the most important problems and measures connected with the correction of the consequences of enemy nuclear strikes on cities.

3.31. What are the basic requirements that commanders and staffs must consider in stationing troops in woods? Explain!

3.32. Describe the possible effects of a nuclear weapon detonation on the field fortification and barrier system.

3.33. Why, after enemy nuclear strikes, can we only get a rough picture of the developing situation as a result of analysis? What conclusions do you draw from that?

3.6. Notes for Chapter 3.

1. Concerning the concept of reduced detonation depth, see Section 2.1.2.

2. Violet, Ch. E., Mining Songr. J., 1960, 3, p 79, quoted from Nifontov, B. I., and others, "Underground Nuclear Detonations," Moscow, 1965, p 157, Russian.

3. See also DV [Service Regulation]-66/3, 1963, pp 127 ff.

4. The diagrams in figures 3.8-3.10 were--partly redrawn--taken from "The Effects of Nuclear Weapons," Washington, 1962; Russian edition of the above-mentioned work obtainable from the Publishing House of the USSR Defense Ministry, Moscow, 1965, p 130 or p 132.

5. "Effect of blast wave after nuclear weapon detonations," MILITAERTECHNIK, 1964, p, p 164, and, 1964, 6, p 204; Klose, K., "The Blast Wave as an Annihilation Factor after Nuclear Weapon Detonations and Its Effect on Installations," MILITAERTECHNIK, 1964, 4, p 166 and, 1969, 5, p 166.

6. Concerning this problem complex, see also Jastak, Z., "Informator o skutkach dzialania broni jadrowej," National Defense Ministry, Warsaw, 1971, pp 65 ff.

7. In specific computations of the pressure stress one must keep in mird that it is not only the maximum overpressure along the blast wave front which is decisive but also the developing reflection pressure (see Section 3.2.3.4.). For further details see DV 66/3, 1963, pp 200 ff.

8. The numerical data in this table were taken from Nifontov, B. I, and others, "Underground Nuclear Detonations," Moscow, 1965, p 54, Russian.

9. Carder, D. S., and W. K. Cloud, J. Geophys. Res., 64, 1959, 10, p 1471.

10. Same as Footnote 2, above.

11. The table was taken unaltered from Nifontov, B. I., and others, "Underground Nuclear Detonations," loc. cit., p 70.

12. Data on the intensity of the quake pertain to the 12-step Mercalli-Cancani-Sieberg scale.

13. See among others Klose, K., "The Effects of Nuclear Weapons after Maritime Detonations," MILITAERTECHNIK, 1966, 1, p 14, 1966, 2, p 56, 1966, 3, p 94; article collection, "Kernenergie und Flotte" [Nuclear Energy and the Fleet], DMV [Defense Ministry], Berlin, 1961, translated from Russian; "The Effects of Nuclear Weapons," loc. cit.

14. The photos were take from "The Effects of Nuclear Weapons," loc. cit., pp 193, 204, 236, and 240.

15. Tsivilyev, M. P., and others, "Engineer Activities in the Action Area of a Nuclear Strike," USSR Defense Ministry Publishing House, Moscow, 1968, Russian.

16. Ibid., p 17.

17. Concerning the necessary numerical data for the destruction pressures and the resultant destruction radii, reference is made to pertinent literature sources. See also the nomograms in Chapter 8.

18. The viewpoints presented in this section must among other things also be considered when the nomograms in Chapter 8 are used.

4. Light Radiation from Nuclear Detonation

4.1. General Description of Light Radiation

In addition to the blast wave, light radiation in a series of detonation types represents an additional main annihilation factor. In this kind of estimate however one must keep in mind that the light radiation, in contrast to the blast wave, can spread only in the atmosphere or in an area [space] without air.

Light radiation as an annihilation factor is closely connected with the origin and development of the fireball from a nuclear detonation. This is why the following statements are founded on the basic laws of the fireball which were explained in Section 2.1.1. Repetitions will be presented only to the extent that they seem necessary for an understanding of the general relationships.

Light radiation from a nuclear detonation is a flow [current] of radiation energy in the UV, "visible," and IR spectral range. The source of light radiation is the glowing air as well as the gases and vapors from the original nuclear weapon forming the detonation's fireball.[1]

This definition tells us that the term "light radiation" is used here in the comprehensive sense. This means that we include in light radiation all of the electromagnetic waves emitted by the electron jackets in the range of $5 \cdot 10^{-9}$ to 10^{-4} m. The individual spectral ranges encompass the following wavelengths:

5-400 nm--UV radiation;
400-800 nm--visible radiation;
800-10^5 nm--IR radiation.

This is why the terms "thermal radiation" or "heat radiation" are also customary in the literature on the subject in place of the term "light radiation."

The range visible to the human eye is relatively narrow (0.00078 to 0.00036 mm). In case of a standard nuclear weapon however it only accounts for about 40-50 percent of the total light radiation energy.

The most important characteristic magnitudes of light radiation in addition to the light impulse are its intensity, energy, and spectral composition. These parameters are primarily a function of the fireball's surface temperature and they are connected with the detonation intensity via the duration of illumination and the dimensions of the fireball.

In line with the development of the fireball and the temperature curve along its particular radiating surface, light radiation as we know is emitted in two periods. Here, the first period, up to the attainment of the minimum temperature, accounts for only about 1.5 percent of the total light radiation energy whereas during the course of the second period accordingly about 98.5 percent are released. This is why we will below subject only the light radiation emitted during the second period to closer examination.

The action duration of light radiation during the second period of the fireball encompasses the time interval of:

$$3{,}2 \cdot 10^{-3} \cdot q^{1/3} < t_2 \leq q^{1/3} \quad s \tag{4.1}$$

During this period we have the second maximum temperature at which the fireball's surface temperature, regardless of the detonation intensity, reveals a temperature of about 8,000° K. The time, after detonation, corresponding to this temperature maximum, can be estimated as follows from the detonation intensity:

$$t(T_{max}) = 0{,}065 \cdot q^{1/3} \quad s \tag{4.2}$$

From this point on, the surface temperature goes down steadily until it reaches the temperature range of 1,500-2,000° K where the fireball is extinguished and emission of light radiation is thus terminated.

To determine the fireball's surface temperature it is possible to use the radiation temperature, that is to say, the temperature of a "black body" where the quantity of energy radiated from a surface unit is the same as that from a surface unit of the fireball.[2]

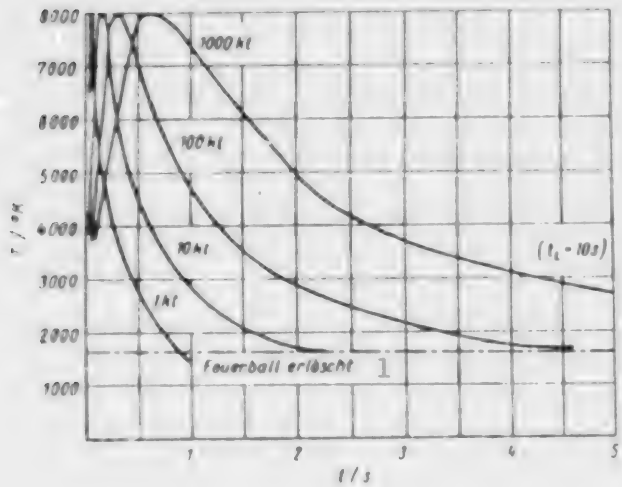


Figure 4.1. Temperature curve along fireball's surface during its second period for detonation intensities of 1, 10, 100, 1,000 kt. Key: 1--Fireball extinguished

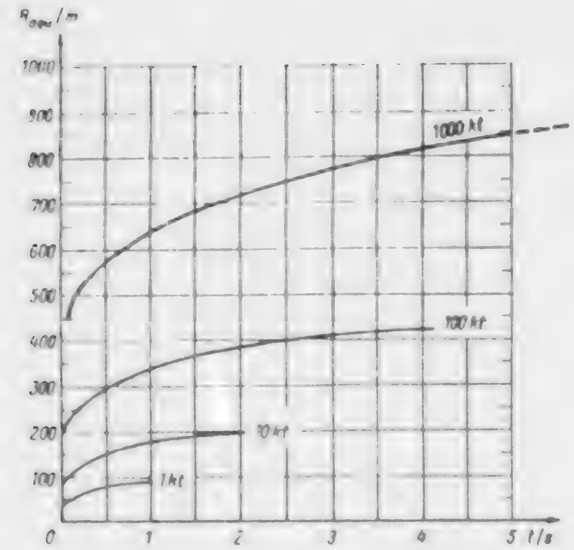


Figure 4.2. Change in equivalent radius of fireball for detonation intensities of 1, 10, 100, and 1,000 kt according to formula 2.5 at time interval t_2.

On this basis, the temperature curve along the fireball's surface is given during the second period for some selected detonation intensities in the graph (Figure 4.1).

The intensity of light radiation, that is to say, the light quantity radiated per square centimeter and second, is connected with the fireball's surface temperature according to the law of Stefan Boltzmann:

$$I_0 = \sigma \cdot T^4 \quad cal\,cm^{-2}\,s^{-1} \tag{4.3}$$

According to this law, the intensity of light radiation is proportional to the 4th power of the thermodynamic temperature. Because of that, a relatively minor temperature in the radiating surface already causes a correspondingly large intensity change.

Here, σ is the Stefan Boltzmann constant, also called radiation constant; it is:

$$\begin{aligned}\sigma &= 1{,}357 \cdot 10^{-12} \quad cal\,cm^{-2}\,s^{-1}\,grd^{-4}\\ &= 5{,}68 \cdot 10^{-5} \quad erg\,cm^{-2}\,s^{-1}\,grd^{-4}\end{aligned}$$

From Formula 4.3 we get the light energy radiated from the entire surface of the fireball with the equivalent radius of R_{equ} (R_{equ} is to be inserted in centimeters) per second, as follows:

$$I_{ges} = 4\pi \cdot R^2_{equ} \cdot I_0 \quad cal\,s^{-1} \tag{4.4}$$

The change in the equivalent radius with the passage of time is illustrated in Figure 4.2. Considering the changes in the surface temperature and the equivalent radius of the fireball having a detonation intensity q with the passage of time, we get the total energy of light radiation emitted during the illumination time $t_1(t_2)$ as follows:

$$E_L = \int_0^{t_L} I_{ges}\,dt = 4\pi \cdot \sigma \int_0^{t_L} T^4(t) \cdot R^2_{equ}(t)\,dt \tag{4.5}$$

On this basis we can approximately estimate the total energy E_L of light radiation from a nuclear weapon detonation as follows:

$$E_L = 3{,}5 \cdot 10^{11} \cdot q \quad cal \tag{4.6}$$

This energy amount roughly corresponds to about 30-40 percent of the total energy from a nuclear weapon detonation in the kiloton range in the atmospheric layer near the ground. For each kiloton of nuclear energy we thus find that more than 300 billion calories are released in the form of light radiation as an annihilation factor.

This energy amount is roughly equivalent to 400,000 kwh of electric energy.

For example, the total light radiation energy from a 20-kt detonation is equivalent to the light energy which, during an average summer day, falls upon a surface area of 4 km^2 (t_L at 20 kt approximately 2.7 sec).

In general we can figure that the share of light radiation out of the total energy from a nuclear detonation decreases as the detonation intensity increases.

Its share at a detonation intensity of about 1 kt is about 40 percent whereas it will only be about 25 percent at 10 Mt.

As we can see in Figure 4.3, the total light radiation energy emitted is distributed very unevenly over the fireball's illumination time.

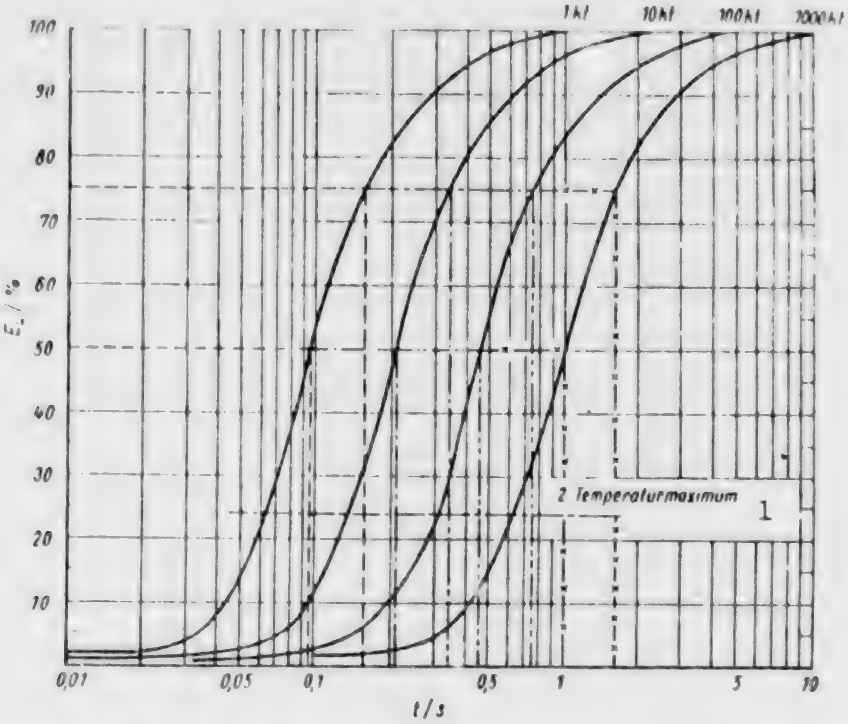


Figure 4.3. Share of radiated light energy out of total light energy as a function of the time after detonation for detonation intensities of 1, 10, 100, and 1,000 kt. Key: 1--Second temperature maximum.

We can thus see that about 90 percent of the total light radiation energy are already released during the first third of the radiation time.

At a 1,000-kt detonation with a fireball illumination time of t_L = 10 sec, the time span of up to about 1 sec after the detonation accounts for 50 percent of the total light energy and the time span of up to 1.7 sec after the detonation accounts for 75 percent. This means that less than 25 percent of the residual energy of light radiation are released during the time interval of 2-10 sec after the detonation. This shows us that, even at greater detonation intensities, with a relatively long illumination time (radiation time) of the fireball, it is necessary to react extraordinarily quickly to light radiation in order to protect oneself effectively.

Protected measures against the blinding effect of a nuclear detonation are also difficult to carry out for the same reason. Just as the intensity and energy of light radiation, so is its spectral composition a function of the fireball's surface temperature which means that it changes constantly during the illumination time.

U--light impulse, cal cm^{-2}; E_L--total energy of light radiation, cal; r--distance from detonation center, cm; q--detonation intensity, kt.

The light impulse is the energy quantity of light radiation which during the fireball's entire radiation time (illumination time) falls on a surface area of 1 cm^2 located perpendicularly with respect to the light radiation's propagation direction. The light impulse is labelled with the symbol U and is expressed in cal cm^{-2}.

Under the conditions of a specific nuclear weapon detonation, one cannot with adequate accuracy determine the developing light impulses according to the relation 4.9. Instead, it is necessary to examine a series of factors most closely, that is, factors which have an essential effect on the propagation of light radiation and one can then accordingly correct the basic formula given.

Specially, the light impulses appearing at the particular distances depend on the following factors:

The summary energy of light radiation E_L (the latter will in the following be assumed to be constant in percentage terms according to Formula 4.6) emitted as a function of the particular detonation intensity;

The detonation altitude or detonation type;

The weather conditions, that is to say, the condition of the atmosphere; the distances from the detonation center.

4.2.1. Influence of Detonation Type on Light Radiation Propagation

The particular detonation altitude and thus the detonation type essentially influence the annihilating effect of light radiation. This fact is due to various causes.

Here we must include the deformation of the fireball, the consumption of a certain part of light energy for melting and evaporation of the ground, and, under certain circumstances, the propagation of light radiation in the air layer near the ground which is severely contaminated with dust and smoke.

The fireball from a nuclear detonation will develop almost undisturbed, that is to say, in a spherical form, only in case of high-altitude air bursts. As the detonation altitude goes down, the reflected blast wave leads to the increased flattening of the fireball along its underside. This means that the size of the fireball's visible surface and the quantity of light energy radiated in various directions will differ in the individual detonation types.

These light radiation propagation conditions, which change depending on the detonation intensity as a function of the detonation altitude, are expressed with the help of the correction factor $k_{H(D)}$.

Because light radiation regarding its spectral composition differs hardly from the radiation of a black body, it is possible to use the corresponding laws for computations with adequate accuracy. According to Wien's transfer law, the wavelength λ_{max}--at which the light radiation intensity reveals its maximum--is shifted toward ever smaller values as the thermodynamic temperature goes up.

Accordingly we have the following relation:

$$\lambda_{max} \cdot T = \text{const} = 0{,}2897 \quad \text{cm grd}$$

$$\lambda_{max} = \frac{0{,}2897}{T} \quad \text{cm}$$

$$\lambda_{max} = \frac{0{,}2897}{T} \cdot 10^{8}\ \text{Å} \tag{4.7}$$

According to the transfer law of Wien (4.7), light radiation will be all the more short-wave and all the more intensive, the higher the fireball's surface temperature happens to be. This means that, at the start of radiation time, the maximum of emitted light radiation will be in the UV range and that it will then shift toward the end of the fireball's illumination time via the visible into the IR spectral range.

The maximum spectral intensity $I_{\lambda_{max}}$ of light radiation for the particular surface temperature of the fireball can be determined according to the following relation:

$$I_{\lambda_{max}} = 3{,}1 \cdot 10^{-20}\, T^{5} \quad \text{cal cm}^{-2}\, \text{Å}^{-1} \tag{4.8}$$

On the basis of the values of λ_{max} and $I_{\lambda_{max}}$ we can also calculate the spectral intensities for other wavelengths.

If we finally integrate the spectral intensities for the characteristic ranges, then we get the approximate distribution as a function of the fireball's surface temperature as given in Table 4.1. Because light radiation of varying wavelengths is attenuated in a different manner on its way through the atmosphere, its composition will likewise change with the distance from the detonation center.

Table 4.1. Guidance Values on Spectral Composition of Light Radiation during the Second Phase of Fireball Illumination Time

Oberflächen-temperatur des Feuerballs °K (1)	prozentualer Energieanteil der einzelnen Spektralbereiche am Gesamtspektrum (2)		
	ultraviolett (3)	sichtbar (4)	infrarot (5)
8000	31	48	21
7000	22	48	30
6000	13	47	40
5000	7	41	52
4000	2	27	71
3000	–	12	88
2000	–	3	97
1500	–	–	100

Key: 1--Fireball's surface temperature; 2--Energy percentage share of individual spectral ranges out of total spectrum; 3--UV; 4--Visible; 5--IR.

In the immediate detonation area we can by way of approximation figure on an average spectral composition, over the illumination time, amounting to 20 percent (UV), 40 percent (visible), and 40 percent (IR); on the other hand, at a distance of 8 km, the figures are 10, 40, or 50 percent.[3]

Review Questions

4.1. Explain the most important characteristic magnitudes of light radiation from a nuclear detonation.

4.2. Why is it possible in many calculations to neglect the first period of the fireball?

4.3. What conclusions can be drawn from the uneven distribution of the total light energy over the fireball's illumination time?

4.4. On what factors does the spectral composition of light radiation from a nuclear detonation depend?

4.2. Propagation of Light Radiation

If we start with undisturbed development of the fireball from a nuclear detonation and if we neglect the attenuation of light radiation by the atmosphere, then light radiation will spread along a straight line and uniformly in all directions at a speed of 300,000 km sec^{-1}.

If we furthermore consider the fireball as a point-shaped radiation source for the computation of this propagation, then the surface area F, covered by light radiation, will grow with the square of the distance r from the detonation center. Depending on the detonation intensity q, the following relation then applies according to Formula 4.6.

$$U = \frac{E_L}{4\pi \cdot r^2} = \frac{3{,}5 \cdot 10^{11} \cdot q}{4\pi \cdot r^2} \quad \text{cal cm}^{-2} \tag{4.9}$$

The correction factor $k_{H(D)}$ depends on the detonation altitude and the detonation intensity. It is a measure of the distortion of the fireball and thus of the differing propagation of light radiation in various directions.

The values for $k_{H(D)}$ are in the range of 0.7 (contact detonations) up to 1 (high-altitude air bursts). They can be seen in Figure 4.4.

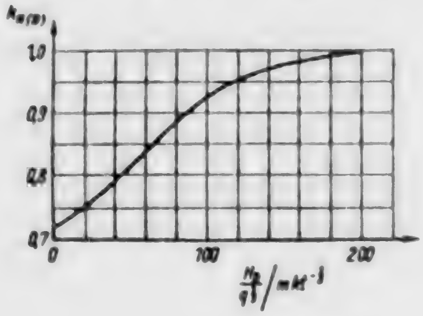


Figure 4.4. Values for the correction factor $k_{H(D)}$.[4]

For ground bursts, it is necessary to introduce an additional correction factor.

As we know, the fireball touches the ground in case of a ground detonation. This causes a part of the earth to melt and vaporize in the area of the developing crater as well as the ejection of large masses of dirt and slag.

Because of that, the part of light radiation which spreads in the direction of or along the earth's surface, is attenuated considerably more than the light radiation radiated into the open atmosphere. Furthermore, a part of the fireballs's surface facing toward the earth is in fact completely screened by the dust swept up by the detonation.

The correction factor $k_{ED(q)}$ depends on the detonation intensity. It is a measure of the screening effect of the swept-up dust. The greater the detonation intensity, the greater the fireball's illumination time and the climbing height of the dust column and consequently also its screening effect on objects located on the earth's surface.

The values for $k_{ED(q)}$ are in the range of 1 (1 kt) to 0.25 (1 Mt). This tells us that the effective light impulses after ground and air bursts can differ greatly from each other even though the distances may be the same.

Table 4.[illegible]. Values for the Correction Factor $k_{ED(q)}$

q/kt	1	10	20	30	50	100	200	500	1000
$k_{ED(q)}$	1	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,25

For rough calculations of up to about 100 kt one can--regardless of the situation explained above--make the factors $k_{H(D)}$ and $k_{ED(q)}$ equal to 1.

In case of underground detonations, the light radiation going beyond the immediate detonation area does not appear as an annihilation factor.

In other words, it is almost completely absorbed by the earth or the ejected dust and ash masses. Something similar applies to underwater detonations.

4.2.2. Attentuation of Light Radiation during Passage Through Atmosphere

The attenuation of light radiation by the atmosphere is superposed on the decrease in the magnitude of light impulses with the square of the distance from the detonation center as expressed in Formula 4.9.

There are two phenomena which are of interest here: Absorption and scatter.

The absorption of light radiation takes place through the molecules of the air or through contamination and admixtures (dust, water vapor).

Ozone in particular absorbs UV radiation while water vapor absorbs IR radiation. This means that the polychromatic light radiation from a nuclear detonation will be absorbed in different ways as a function of the state of the atmosphere.

The term "scatter" means the deflection of light radiation from its original propagation direction. Light of all wavelengths is scattered. This takes place through the gas molecules as well as dust, smoke, and fog particles. Molecular scatter however is minor and therefore can generally be overlooked; that is to say, the aerosol scatter is decisive.

Here, the scatter reaches very high values particularly when the magnitude of the particles is roughly equal to the wavelength. It follows from this that light radiation of varying wavelength is scattered in various ways.

It is understandable that only the part of light radiation that is absorbed is not further propagated. If one nevertheless in a first approximation neglects the further path of scattered radiation, then attentuation coefficient of the air can be expressed as the sum of the absorption coefficient K' and the scatter coefficient K^+:

$$K = K' + K^+ \qquad (4.10)$$

Here both K' and K^+ and thus also K represent average values, that is to say, we start with an average attenuation for the entire spectrum of light radiation.

The connection between the attenuation coefficient K and the state of the atmosphere is established via the visual range S.

The visual range characterizes the distance at which the outlines of a big black body can still be distinguished in daylight on the horizon

Assuming that we figure the contrast threshold value ε to be 0.02, we get the following.

$$S = \frac{1}{K} \ln \frac{1}{\varepsilon} = \frac{1}{K} \ln \frac{1}{0{,}02} \approx \frac{3{,}9}{K} \quad \text{km}$$

and

$$K \approx \frac{4}{S} \quad \text{km}^{-1} \tag{4.11}$$

Summarizing we can say the following on the basis of what we have said so far:

If we neglect the scattered radiation, the values of the light impulses from a nuclear detonation decrease because of the attenuation of light radiation during passage through the atmosphere while traveling the distance r from the detonation center by the magnitude $e^{-K(r-R)}$, whereby R is the radius of the fireball at the time of the second temperature maximum.

But one must not assume that the magnitude of the light impulses at the particular distances is a simple function of the visual range. Instead, each light impulse is made of direct and scattered radiations. It was pointed out earlier that, in the case of the attenuation of light radiation, basically only the share of the absorbed light energy is lost for further propagation while the scattered portion remains preserved.

Table 4.3. Visual Ranges, Attenuation Coefficients, and Permeability Factors (1) as a Function of the State of the Atmosphere

2 Zustand der Atmosphäre	3 Sichtweite S km	4 Schwächungs-koeffizient K km^{-1}	5 Durchlässig-keitsfaktor e^{-K}
6 außerordentlich reine Luft (große Entfernung von den Städten)	100	0,04	0,96
7 reine Luft (außerhalb von Städten)	40	0,1	0,91
8 Luft mittlerer Reinheit	20	0,2	0,82
9 verstaubte Luft (innerhalb großer Städte)	10	0,4	0,67
10 Dunst	4	1	0,37
11 leichter Nebel	< 2	> 2	< 0,14
12 Nebel	< 1	> 4	< 0,02

Key: (1) Various publications combine e^{-K} to simplify the calculations into the so-called permeability factor; this numerical value then expresses the ratio between the light energy that is emitted from an air layer with a thickness of 1 km and the energy that has entered that layer; 2--State of the atmosphere; 3--Visual range S; 4--Attenuation coefficient K; 5--Permeability factors; 6--Extraordinarily clear air (long distance from cities); 7--Clean air (outside cities); 8--Air of average purity; 9--Dust-containing air (inside big cities); 10--Haze; 11--Light fog; 12--Fog.

Feller among others pointed out that the most important thing in the scatter is the heavy predominance of forward scatter.[5] In other words, this means that, as the air becomes increasingly clouded the share of scattered light radiation grows because of the higher aerosol portion.

This is why the attenuation of light radiation at short visual ranges can remain relatively constant over vast areas. In this case, in other words, the attenuation can no longer be expressed with adequate accuracy by the attenuation coefficient K. The transmission factor T_f was introduced for these reasons; it allows for the further path of scatter radiation.

The transmission factor T_f, often used as basis for attenuation calculations in the propagation of light radiation in the atmosphere, is a complex (highly complicated) function of the absorption and scatter (visual range) and the distance from the detonation center.

The values of the transmission factor T_f are illustrated for visual ranges of 16 km and 80 km in Figure 4.5.

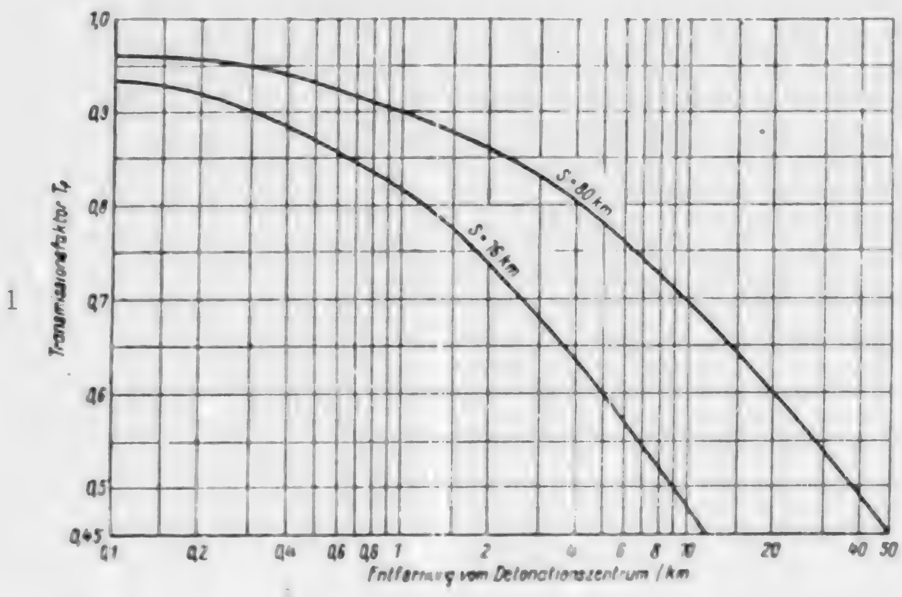


Figure 4.5. Values of the transmission factor T_f as a function of the distance from the detonation center for visual ranges of 16 km and 80 km.[6]
Key: 1--Transmission factor T_f; 2--Distance from detonation center, km.

The values in Figure 4.5 can be used with adequate accuracy if the distances r from the detonation center do not exceed half the visual range.

Further explanations on this problem complex are given in Section 4.2.3.

4.2.3. Change in Magnitude of Light Impulses as Function of Detonation Altitude and Distance from Detonation Center (Ground Zero)

In both of the preceding sections, we covered the influence of a nuclear weapon detonation type and the state of atmosphere on the propagation of light radiation in an elementary form; it is now possible more exactly to describe the change in the magnitude of the light impulses with the distance from the detonation center through the introduction of the corresponding correction factors or coefficients in basic equation 4.9.

Considering the units of measure, in which the individual magnitudes are to be connected with each other in a numerical value equation, we get the following expression for the magnitude of a light impulse U at distance r from the detonation center:

$$\frac{E_L}{4\pi \cdot r^2} \cdot k_{H(D)} \cdot k_{ED(q)} \cdot e^{-K(r-\bar{R})}$$

Because the values must be inserted uniformly in kilometers for r and [blank space in original], in keeping with definition of K already given, we get the following:

$$U = \frac{3.5 \cdot 10^{11} \cdot q}{4 \cdot 10^{10} \cdot \pi \cdot r^2} \cdot k_{H(D)} \cdot k_{ED(q)} \cdot e^{-K(r-\bar{R})}$$

and we get the following after combination:

$$U = 2.8\,\frac{q}{r^2} \cdot k_{H(D)} \cdot k_{ED(q)} \cdot e^{-K(r-\bar{R})} \quad \mathrm{cal\,cm^{-2}}$$

q--detonation intensity, kt; r--distance from detonation center, km; $\bar{R}$--radius of fireball at time of second temperature maximum, km; the following applies: $\bar{R} = 0.055 \cdot q^{2/3}$; K--air attenuation coefficient, km^{-1}; $k_{H(D)}$, $k_{ED(q)}$--coefficients according to Section 4.2.1 or 4.2.2.

The way to use Formula 4.12 becomes clear in the following example.

Problem: Estimate the magnitude of the light impulse to be expected from the detonation of a nuclear weapon with q = 20 kt and H_D = 300 m and a visual range of S = 20 km at a distance of 400 m from groung zero.

Solution:

1) The distance from the detonation center is:

$$r = \sqrt{(400\ \mathrm{m})^2 + (300\ \mathrm{m})^2} = 500\ \mathrm{m} = 0.5\ \mathrm{km}$$

(2) The attenuation coefficient K can be calculated as follows according to Formula 4.11:

$$K = \frac{4}{20\ \text{km}} = 0{,}2\ \text{km}^{-1}$$

(3) The radii $\bar{R}$ of the fireball is calculated as follows:

$$\bar{R} = 0{,}055 \cdot 20^{2/5} = 0{,}18\ \text{km}$$

(4) For H_D = 300 m, the attenuation factor values are as follows:

$$k_{H(D)} = 0.95 \text{ (Figure 4.4) and } k_{ED(q)} = 1$$

(5) According to Formula 4.12, we get the following by inserting the given or calculated numerical values:

$$U = 2{,}8\,\frac{20}{0{,}5^2} \cdot 0{,}95 \cdot 1 \cdot e^{-0{,}2\,(0{,}5-0{,}18)}$$

$$U \approx 200\ \text{cal cm}^{-2}$$

In section 4.2.2 we already pointed out that Formula 4.12 gives us light impulse values which are too low because we did not consider the forward scatter in case of short visual ranges.

This is why it is better under such conditions if one works with the transmission factor T_f and initially neglects the correction factors $k_{H(D)}$ and $k_{ED(q)}$, that is to say, if we set them equal to 1. Similar to 4.12, we then get the following expression:

$$U = 2{,}8\,\frac{q}{r^2} \cdot T_f \quad \text{cal cm}^{-2} \tag{4.13}$$

If we solve the above problem with the help of Formula 4.13 (for T_f we get the value of 0.87 from the illustration in Figure 4.5 for a visual range of S 16 km) then we get the following:

$$U = 2{,}8\,\frac{20}{0{,}5^2} \cdot 0{,}87 \approx 195\ \text{cal cm}^{-2}$$

This constitutes good agreement.

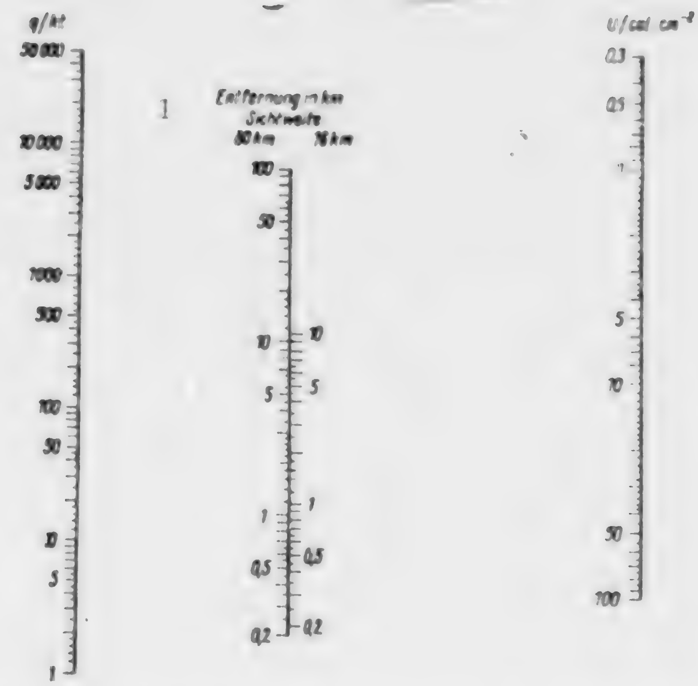


Figure 4.6. Nomogram to estimate the magnitude of light impulses as a function of the detonation intensity and the distance from the detonation center according to Formula 4.13 for visual ranges of 16 km and 80 km.[7] Key: 1--Distance in km, visual range.

With the help of the nomogram (Figure 4.6) it is possible approximately to determine the magnitude of the light impulses as a function of the distance from the detonation center.

As we said earlier, the light impulses from ground bursts at the particular distances from the detonation center are smaller than from air bursts of equivalent intensity. This why it is necessary to correct the nomogram values.

The correction factor values are in the range of 0.8 at short distances from the detonation center ($r \leqq 0.5$ S) to 0.5 at great distances ($r > 0.5$ S).

Formula 4.13 can then be written as follows:

$$U = (0.5 \quad 0.8) \cdot 2.8 \frac{q}{r^2} \; T_t \quad \mathrm{cal\,cm^{-2}} \qquad (4.14)$$

If one assumes the energy share of light radiation out of the total energy from a nuclear detonation to be constant, as in formulas 4.12 and 4.13, then the magnitudes of the light impulses will change directly proportionally to the detonation intensity. This applies at long visual ranges in the kiloton range also for rough calculations on the annihilating effect of light radiation. This law is sometimes referred to as the similarity law of light radiation.

Just which of the ways explained in section 2.2.3 we use to calculate the magnitude of light impulses will depend on the required accuracy. But we

should avoid exaggerated accuracy requirements because it is hardly possible to recall all influencing magnitudes connected with a specific nuclear weapon detonation with equal exactness.

4.2.4. Additional Factors Acting upon Light Radiation Propagation

The propagation of light radiation in the atmosphere and its annihilating and damaging effects--particularly on objects on the earth's surface--are essentially influenced by the weather conditions prevailing at the time of detonation and the terrain conditions in the near and far detonation area. In making this kind of statement one must keep in mind that the range of damaging light radiation can by far exceed the range of other instantly acting annihilation factors.

4.2.4.1. Influence of Meteorological Conditions

The influence of meteorological conditions on the magnitude of the light impulses at the particular distances from ground zero goes far beyond the state of the atmosphere characterized by the visual range. Here we are above all interested in cloud cover and precipitation.

Depending upon the detonation altitude and the cloud cover altitude, a nuclear weapon detonation can take place below or above a cloud cover or also in the clouds. In any case, there is a scatter or reflection of light radiation along the particular boundary surface as a result of which there is a change in the direction of radiation and thus an altered energy distribution in terms of space.

From this angle, clouds can have a reducing or increasing effect on the magnitude of the light impulses appearing along the earth's surface.

One may thus assume, for example, that, after a nuclear detonation in the kiloton range, below a compact cloud cover, the light impulse values along the earth's surface will be as much as 50 percent higher. In addition we have the fact that the scatter also provides a possibility of influencing those areas which, because of the straight-line propagation of light radiation, normally remain in the shade.

The share of light radiation absorbed during passage through a cloud cover is small and amounts to only a few percent per kilometer.

A haze, fog, or dust layer can be of very great significance in reducing the annihilating effect of light radiation; this of course would be a layer that would have to be between ground zero and the object observed. For example, the United States in 1954 ("Not Hole" nuclear test) and in 1955 ("Teapot" nuclear weapon test) used fog [smokescreen] curtains for protection against light radiation. Remote-controlled smoke generators were used during these tests. The smokescreen was put up before the detonations and lasted about 10 min. Here, the light impulse values were reduced by 65-90 percent, depending upon the distance from ground zero. This resulted in a reduction of the light radiation's action zone with respect to the area of severe blast wave effects.

The properties of this kind of protective smokescreen are primarily determined by its extent, by the size of the fog [smokescreen] particles, and the color of the smokescreen. According to Klose, white fog can absorb up to 30 percent and black fog can absorb up to 80 percent of the light energy.[8] Under field conditions however the large-scale use of protective smokescreens is countered by some restrictive aspects. Here we might merely refer to the great need for smokescreen equipment which may arise from the need for providing a longer-lasting smokescreen for large surface areas. At the same time however the use of a smokescreen is also connected with a certain unmasking effect. This is why one must consider the use of "pure" protective smokescreens as the exception.

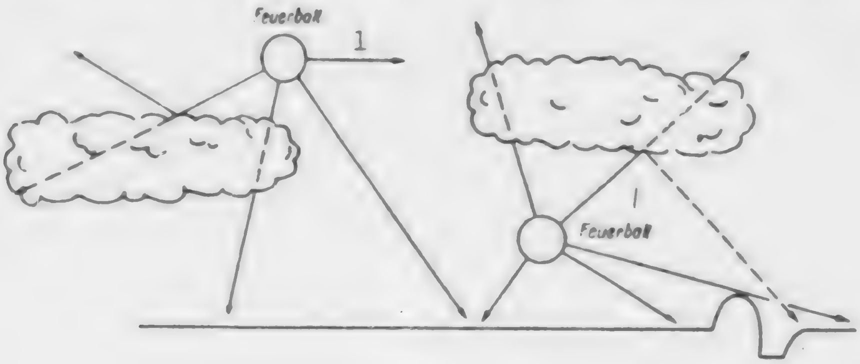


Figure 4.7. Influence of cloud cover and light radiation propagation.
Key: 1--Fireball

Precipitation in the form of rain or snow at the moment of detonation can so heavily weaken light radiation that it will practically no longer appear as an independent annihilation factor over larger distances. On the other hand, a compact snow blanket will considerably increase the annihilating effect of light radiation because--due to the strong reaction capacity of snow and ice--an average of about 50 percent of the incident light radiation will be reflected. In this connection, we can get multiple scatter of light radiation in conjunction with a more or less compact cloud cover.

4.2.4.2. Influence of Terrain

The influence of the terrain on the propagation of light radiation is present in two ways: Due to the terrain relief and due to the vegetation cover or man-made structures.

Depending on the relative detonation altitude, shadow zones or areas develop along the reverse slopes of mountains, hills, valleys, or gorges; in these zones or areas, the effect of light radiation is barred or more or less heavily diminished. For an approximate estimate we can assume that those objects will be in such shadow zones for which the following condition applies:

$$\operatorname{tg} \alpha > \frac{H_{D'} + R_{Feu(max)}}{r_0} \qquad (4.15)$$

α--slope's angle of inclination; H_D'--relative detonation altitude with relation to the object observed; $R_{equ\ (max)}$--maximum equivalent radius of fireball; r_0--distance from ground zero to object on reverse slope.

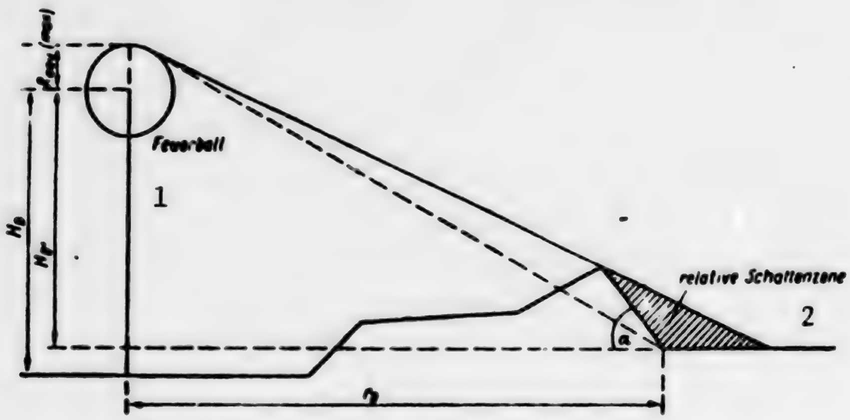


Figure 4.8. Development of Shadow Zones after Nuclear Weapon Detonations
Key: 1--Fireball; 2--Relative shadow zone.

It follows from Formula 4.15 that, for example, for a 20 kt nuclear detonation at a relative detonation altitude of 300 m we must have the inclination angle $\alpha > 30°$ at 1 km from ground zero, $\alpha > 15°$ at 2 km distance, and $\alpha > 10°$ at 3 km distance, if such a shadow zone is to be formed. These numerical values show that one must not overestimate the influence of the terrain relief on light radiation propagation especially in case of high-altitude air bursts and high-altitude detonations. In addition we have the fact that one must also figure on scatter radiation in the shadow zones. Regardless of that, the correct exploitation of pertinent protective properties offered by the terrain can considerably reduce the annihilation radius of light radiation.

A major decrease in the effective light impulses appears inside more or less vast forest massifs. Here naturally many factors play a role, such as the types of trees, the density and the height as well as the season. As guidance values we can assume that a dense forest will reduce light radiation by 80-90 percent whereas a light forest will reduce it by 50-80 percent.

In interpreting this fact one must however consider the danger of fires which is extremely great in woods (depending on weather conditions and the season).

Of course, narrowly limited shadow regions--which cause a decrease in the annihilating effect of light radiation--are also formed after nuclear detonations if one neglects the scatter radiation particularly with increasing distance and behind relatively low rises, such as dams and buildings.

Review Questions

4.5. Explain the concept of the light impulse.

4.6. What factors essentially influence the propagation of light radiation after nuclear detonations?

4.7. Why do we get differing light impulses after air bursts and ground bursts of equal intensity at the particular distances from ground zero?

4.8. Describe the attenuation of light radiation by the processes of scatter and absorption in the atmosphere.

4.9. Why is it as a rule more difficult to estimate the light impulses appearing at corresponding distances from the detonation center than to calculate the analogous overpressure values?

4.10. Explain the influence of weather and terrain conditions on the size of the light radiation action zones.

4.11. What basic conclusions can one draw for the protection of groups against the annihilating effects of light radiation from the situation explained in Section 4.2?

4.3. Annihilating Effects of Light Radiation and Protection against Them

The share of light radiation out of the total effects deriving from a nuclear detonation can under certain conditions be very large. Light radiation causes fires, it leads to skin burns particularly on unprotected parts of the body and causes eye damage in the form of temporary blinding or even permanent blinding.

Under normal visibility conditions, it is typical of light radiation that it can act upon unprotected persons also at ranges at which the blast wave and instant nuclear radiation no longer appear as annihilation factors. It can therefore determine the maximum distances for possible injuries. At a detonation intensity of 20 kt, we have light skin burns up to distances of 4,000 m whereas we have light blast wave injuries up to distances of 900 m. There are analogous values 20,000 m and 4,000 m for a detonation intensity of 1 Mt.

4.3.1. Conversion of Light Impulse as Light Radiation Hits Obstacle

The effect of light radiation from a nuclear detonation on a body supplies energy to that body. At equal light impulse magnitude, different bodies absorb varying quantities of energy. In each case however the energy supply is equivalent to a temperature rise.

The degree to which a body is heated depends on the magnitude of the incident light impulse, the color and nature of the body surface, its thickness, its physical and chemical properties, as well as the angle of incidence of light radiation.

As a result of a correspondingly major temperature rise, a body can catch fire, it can become charred, it can melt, or it can become vaporized.

Light radiation hitting a body is absorbed by the body, it goes through it, such as is the case with transparent materials, or it is reflected from its surface.

The distribution of the particular light impulses over absorption, reflection, and penetration is determined not only by the particular material but primarily by the color of the body and its surface conformation. Because only that part of the light impulse which is absorbed by the body takes effect in terms of heating and thus in terms of the temperature rise, it is especially the bodies which reveal a large absorption coefficient that are greatly influenced by light radiation. In each case it is true that the sum of the absorption, reflection, and penetration coefficients is 1.

$$k_a + k_r + k_d = 1 \qquad (4.16)$$

Because the light impulse is defined for a surface which is perpendicular to the direction of propagation of light radiation, the effect will be reduced if the angle of incidence $\phi > 0°$ at which light radiation hits the body.

From the relationship illustrated in Figure 4.10, we get the effective light impulse as follows:

$$U' = U \cdot \cos\varphi \qquad (4.17)$$

and due to the introduction of the absorption coefficient k_s it finally follows that:

$$U_w = U \cdot \cos\varphi \cdot k_a \quad \text{cal cm}^{-2} \qquad (4.18)$$

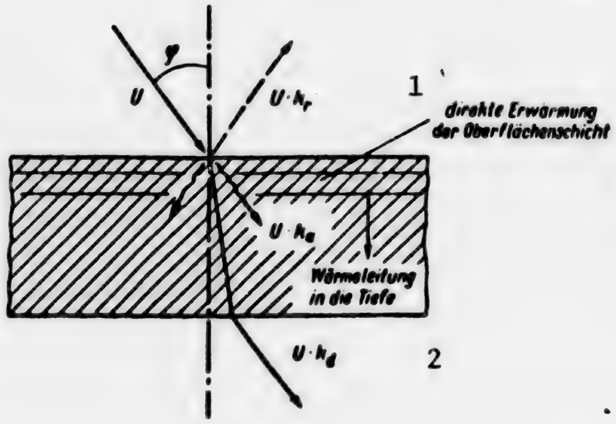


Figure 4.9. Distribution of light impulse over absorption, reflection, and penetration. Key: 1--Direct heating of surface layer; 2--Heat conduction in depth.

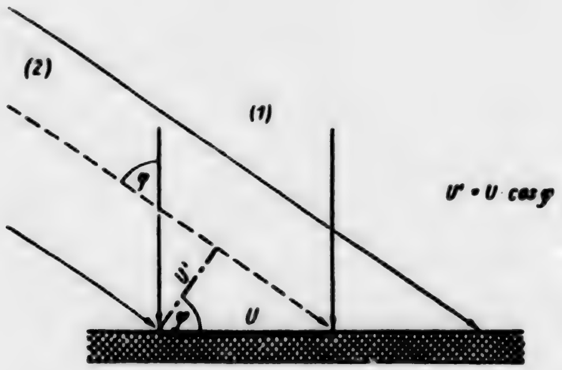


Figure 4.10. Dependence of effective light impulse U' on the angle of incidence ϕ of light radiation.

U_W is called the heat impulse. If we assume in a greatly simplified fashion that this heat impulse is absorbed only on the surface of a solid body, then it characterizes that energy which enters that body per square centimeter of surface.

Thermal energy is supplied to an irradiated body--although not uniformly distributed--during the entire radiation time of the fireball. Simultaneously with the temperature rise on the body surface, caused by this energy supply, heat is diverted into the depth of the body and it is conducted by convection and radiation from the surface as well as by the gases originating during pyrolysis.

This is countered by the fact that an additional temperature rise can be caused by certain chemical processes.

If we reduce all these complicated processes to the most essential interrelationships, we find that the anticipated temperature rise along the irradiated body surface depends on the following factors:

The effective heat impulse (U_W/cal cm^{-2});

The fireball's radiation time (t_L/s);

The heat conductivity (λ/cal cm^{-1} sec^{-1} $degree^{-1}$);

The heat storage capacity (c_γ/cal cm^{-3} $degree^{-0}$) and

The body's thickness (d, cm).

In this connection we mean by the term "heat storage capacity" c_γ the product of the specific heat capacity (c/cal g^{-1} $degree^{-1}$) and the density (ρ/g cm^{-3}).[9]

Concerning the thermal-physical properties of a solid body, the temperature rise in the irradiated surface will be all the greater, the less is its heat conductivity and the greater is its heat storage capacity. Table 4.5. contains some guidance values for a temperature of 20° C. The body's thickness

very essentially influences the maximum temperature rise in the irradiated surface. A corresponding classification is given for example by Feller.[10]

Table 4.4. Values for the Absorption, Reflection, and Penetration Coefficients for Several Materials

	Material	1 Koeffizienten Absorption (k_a)	2 Reflexion (k_r)	3 Durchdringung (k_d)
4	Metalle			
5	Aluminium (poliert)	0,25	0,75	0
6	Eisen und Stahl (bearbeitet)	0,45	0,55	0
7	Eisen und Stahl (nicht bearbeitet)	0,90	0,10	0
8	Baumaterial			
9	farbloses, durchsichtiges Glas (3 mm)	0,02 ··· 0,07	0,08 ··· 0,03	0,9
10	Fichtenbretter	0,7	0,3	0
11	rote Mauersteine und Dachziegel	0,8	0,2	0
12	Rauhputz	0,8	0,2	0
13	Dachpappe	0,95	0,05	0
14	Papier und Gewebe			
15	weißes Seidengewebe	0,05	0,35	0,6
16	weißes Baumwollgewebe	0,08	0,35	0,57
17	weißes Papier	0,15 ··· 0,20	0,65 ··· 0,7	0,2 ··· 0,1
18	Segeltuch, Zeltleinwand	0,75	0,25	0
19	khakifarbene Bekleidung	0,97	0,03	0
20	schwarzer Samt	0,99	0,01	0
21	Farben auf undurchsichtigem Material			
22	weiß	0,1 ··· 0,3	0,9 ··· 0,7	0
23	gelb	0,4 ··· 0,6	0,6 ··· 0,4	0
24	grün	0,6 ··· 0,7	0,4 ··· 0,3	0
25	schwarz	0,9	0,1	0
26	Sonstiges			
27	menschliche Haut (Mittelwert)	0,65	0,35	0
28	Nadelwald	0,85	0,15	0

Key: 1--Coefficients; 2--Reflection; 3--Penetration; 4--Metals; 5--Aluminum (polished); 6--Iron and steel (processed); 7--Iron and steel (not processed); 8--Construction material; 9--Colorless, transparent glass (3 mm); 10--Pine boards; 11--Red bricks and shingles; 12--Rough cast [finished]; 13--Roofing tar paper; 14--Paper and fabrics; 15--White silk fabric; 16--White cotton fabric; 17--White paper; 18--Sail cloth, tent canvas; 19--Khaki-colored clothing; 20--Black velvet; 21--Colors on nontransparent material; 22--White; 23--Yellow; 24--Green; 25--Black; 26--Miscellaneous; 27--Human skin (average); 28--Evergreen forest.

Table 4.5. Guidance Values for Heat Conductivity λ and Heat Storage Capacity c_γ of Some Substances

	Material	1 Wärmeleitfähigkeit cal cm^{-1} s^{-1} grd^{-1}	2 Wärmespeichervermögen cal cm^{-3} grd^{-1}
3	Kupfer	0,94	0,84
4	Aluminium	0,60	0,58
5	Stahl (Mittelwert)	0,11	0,92
6	Beton (lufttrocken)	0,002	0,45
7	Ziegelmauer (Mittelwert)	0,002	0,35
8	Holz (quer zur Faser)	0,0002 ··· 0,0005	0,25
9	Gummi (Mittelwert)	0,0004	0,40

Key: 1--Heat conductivity; 2--Heat storage capacity; 3--Copper; 4--Aluminum; 5--Steel (average); 6--Concrete (air-dried); 7--Brick wall (average); 8--Wood (laterally with respect to the fiber); 9--Rubber (average); grd--degree.

Thick bodies do not reveal any temperature rise on the reverse side at high surface temperature.

Medium-thick bodies reveal only a minor temperature rise on the reverse side with uneven temperature curve.

Thin bodies finally develop the same surface and reverse side temperature with linear temperature pattern.

The problem in this kind of approach however consists in the fact that matching up a body with these three categories does not depend just on the thickness. Instead, this matchup is also a function of the action time of light radiation and it thus changes depending on the detonation intensity.

Attempts to get around the attendant difficulties by defining a so-called effective light impulse (U_{eff}/cal/cm^{-2}s^{-1}2) however do not lead anywhere and do not bring about satisfactory agreement between the theoretically computed values and the corresponding test results.[11]

The surface temperature of a 2-cm steel plate will rise by 7° C in case of a light impulse of 2 cal/cm^{-2} (50 kt), while a 0.2 mm piece of sheet iron will be heated by about 100° C under the same conditions.

At a detonation intensity of 100 kt, steel must have a minimum thickness of about d = 1 cm in order to be included in this category of thick bodies; at q = 20 mt, d must be at least 2 cm.

In case of small detonation intensities, for example, a light impulse of 1 cal/cm^2 will raise the surface temperature more than in case of high detonation intensities.

In order nevertheless to give the reader an idea as to the order of magnitude of occurring temperature rises, we present some numerical values below for a light impulse of 1 cal cm^{-2} when q = 20 kt.

The temperature rise is approximately as follows in case of:

Armor plating: 2-3° C
Fresh boards: 30-50° C
Stored boards: 60-100° C
Red roofing tiles [shingles]: 50° C
Human skin: 5-7° C.

For practical purposes of nuclear weapon protection we do not directly work with the heat impulses but instead we give light impulses which cause the corresponding effects.

Because of the above-explained complicated interrelationships however it is often difficult to make exact, generally valid theoretical statements; this is why we usually fall back on experimental results. In this way we get relatively simple possibilities for performing the necessary calculations.

Table 4.6. Guidance Values for Magnitude of Light Impulses at which Various Materials Can Catch Fire

Material or object	Critical light impulses cal cm^{-2}	
	1 kt	1 Mt
Newspaper, torn	2	3
Newpaper, rotten, crumpled	2	5
Underbrush fires, dry weather	3	5
Kindling wood (dry, rotten wood)	3	7
Fires in residential buildings	4	7
Fine grass	4	8
Fallen leaves	5	9
Coarse grass, pine needles	5	13
Hay	6	8
Wooden structures, weathered	6	10
Tent canvas	7	14
Normal clothing	5...10	10...20
Pine boards, dry	30	70

Various publications to some extent present different figures. There is a series of reasons for that. That includes not only differing experimental conditions but also deviating generalizations or interpretations of results obtained. This is quite understandable because of the many possible influencing factors. We are therefore primarily interested only in the order of magnitude of the effects to be anticipated.

The "critical" light impulses given in Table 4.6 are to be considered minimum values at which one must expect fires to break out under normal weather conditions (dry weather).

At first, there will be individual fires which later on, under certain conditions, will merge into continuing fire areas. To be able fully to set the particular object aflame (at the moment of detonation), on the other hand, we need light impulses which are by 25-100 percent higher than those mentioned.

In this connection it must be kept in mind that the blast wave as a rule will snuff out the flames at overpressure values of $\Delta p_f > 0.25$ kp/cm^{-2}, corresponding to an air speed of more than 50 m/sec^{-1} in the blast wave front. This is the case particularly with smaller detonation intensities because the blast wave and the light radiation here practically act simultaneously. At higher detonation intensities on the other hand the fires can develop so strongly until the approach to the blast wave front that they can no longer be put out in case of greater distances from ground zero.

In addition we have the fact that, in open surfaces, the fire foci are not as stable as, for example, in covered, heavily-cut terrain or woods. Rough calculations on the effect of fire due to light radiation can be performed in a simple fashion with the help of the values in Table 4.6 and the nomogram in Figure 4.6. This method will be explained with the help of an example.

Problem: Estimate the distance from the detonation center up to which fires can develop in residential buildings after an air blast of q = 100 kt at a visual range S = 80 km.

Solution:

1. From Table 4.6 we can tell that the values for fires in residential buildings are 4 cal^{-2} when q = 1 kt and 7 cal/cm^{-2} when q = 1 Mt.

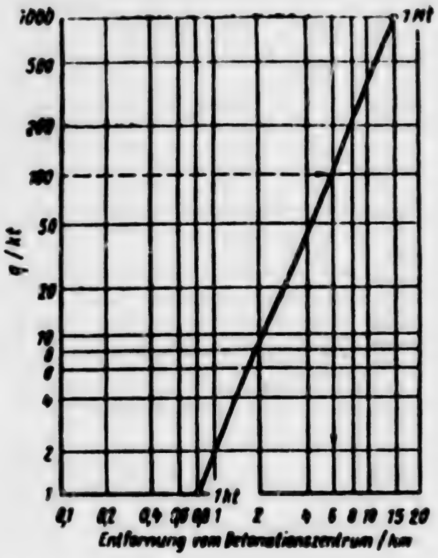
2. From the nomogram (Figure 4.6) we can read off the corresponding distances --for a visual range of S = 80 km--for 1 kt at 0.8 km and for 1 Mt (1,000 kt) at 16 km.

3. These values are plotted on double-logarithmic paper with the distances from the detonation center (km) along the abscissa and the detonation intensities (kt) along the ordinate.

Since both distance figures are connected by a straight line, we can read off the pertinent distances up to which fires are possible in residential buildings for all detonation intensities. When we have q = 100 kt, we get r ≈ 6 km (see Figure 4.11).

4. This value can be converted to the distance from ground, considering the detonation altitude.

In a similar manner we can also determine the distances for charring, burns, etc., if the required initial values are available.



1

Figure 4.11. Determination of action radii of light radiation. Key: 1--Distance from detonation center, km.

4.3.2. Effect on Man and Protection Possibilities

At the time of the detonation in Hiroshima, there were temperatures of 3,000-4,000° C at ground zero and 1,200 m away the temperatures were 1,500° C. With the prevailing very clear visibility, a light pulse of 10 cal/cm^{-2} took effect 2,000 m away from ground zero while it was 2 cal/cm^{-2} 4,000 m away.

In general we can estimate that, under these conditions, in Hiroshima and Nagasaki, 20-30 percent of all injuries were a consequence of the immediate effect of light radiation. Uncovered body parts, face, hands, and arms were particularly hard hit. In Nagasaki, for example, light skin burns were still observed up to a distance of 4 km. As we said earlier in the overview given in Section 3.5.1.1, the damaging effect of light radiation includes primary and secondary burns, blinding, as well as heat stroke. Below we will take up additional questions connected with this.

4.3.2.1. Primary Burns

From what we have just said, it follows that very many factors influence the magnitude of the annihilating effect of light radiation. Here one must particularly note that the effect of light radiation depends far more than the effect of the blast wave on the weather conditions and on terrain conditions.

Light radiation generally can only act on unprotected persons at the moment of detonation. In addition we have the fact that, because of linear propagation, shadow-making objects can still offer relatively good and reliable protection also if we consider a possibly diffuse scatter. This observation is restricted inasmuch as going into cover "at exactly the right time" is possible only to a limited degree because of the immediate effect of light radiation, regardless of the distance.

At any rate, there is a decline in the annihilating effect of light radiation, especially the degree of burns.

Burns due to light radiation are subdivided into primary and secondary burns.

Primary burns are due to the direct action of light radiation on man whereas secondary burns are a consequence of building burns, etc.

As in all other effects deriving from light radiation, the possible primary burns are also a function of the size and duration of the light impulses appearing at the particular distances. In other words, here again it is true that identical light impulses from varying detonation intensities bring about differing effects. Table 4.7 contains some guidance figures.[12]

Primary burns originate from a very intense but relatively short thermal action. They are partly typically represented by serious but as a rule surface burns with scale or scab formation or even charring.

Table 4.7. Guidance Values for Direct Damage to Uncovered Body Parts in Unprotected Persons due to Light Radiation

Degree of damage	Magnitude of light impulses cal/cm^{-2} at 1 kt	1 Mt
1st-degree burns	2	4
2nd-degree burns	4	6
3rd-degree burns	6	8
4th-degree burns	>9	>12

The following external features are characteristic of the individual burn degrees.

1st degree: Reveals all indications of inflammation (pain, heat, reddening, swelling, and functional disorder).

2nd degree: The outermost skin layer (epidermis) is lifted off and blisters are formed; after the blisters burst, the skin and partly also the subcutaneous tissue at this point will die.

3rd degree: Here the surface tissue dies immediately and the part of the body surface thus hit will flake off.

4th degree: It is tantamount to the charring of the tissue.

It is characteristic of primary burns that all shadow-producing objects are very sharply reproduced on the skin, that is to say, undamaged islands at places of shadow formation are clearly differentiated from damaged tissues. In these cases we therefore speak of profile burns. Although uncovered body parts naturally are endangered by light radiation, covered body parts can also be damaged.

Table 4.8. Guidance Values for Gradual Damage of Persons Outside Cover after Air Bursts and with Clear Visibility at Various Ranges (Primary Burns on Uncovered Body Parts) (1)

1 Detonations- stärke kt	2 Grad der Verbrennungen 3 4. Grades	4 3. Grades	5 2. Grades	6 1. Grades
	7 Entfernung vom Nullpunkt/m			
1	400	600	800	1100
10	1400	1800	2200	3000
100	4600	5500	6400	8000
1000	10000	14000	17000	20000
10000	27000	35000	40000	45000

Key: 1--Detonation intensity; 2--Degree of burns; 3--4th degree; 4--3rd degree; 5--2nd degree; 6--1st degree; 7--Distance from ground zero, m; (1) The values given represent maximum distances for the conditions defined because, especially in the case of nuclear detonations in the Megaton range, due to the relatively long action time, one cannot assume that the particular total impulses will become fully effective on the same places on the body. In case of ground bursts, distances with identical effect are reduced by an average of 1/3.

First of all, clothing can be ignited up to a certain distance from the detonation center and can thus lead to skin burns. Here, the material of the clothing, its color, density, and whether it fits tightly on the body, etc., will play a role. In general we can say that wool and linen fabrics are more difficult to ignite than those made of cotton. Bright and loose clothing will provide better protection than dark and closely-fitting clothing. The more clothing items are worn on top of each other, the better will be the protection against light radiation. Besides, damage to covered body parts however is also possible if the incident light impulses are not sufficient to ignite the clothing. Dark clothing in particular will absorb a large part of light radiation, will become more or less strongly heated, and can lead to skin burns. This danger is less in case of bright clothing. In most cases however the latter, especially summer clothing, will be comparatively thin and will thus allow a part of light radiation directly to hit the skin.

Many such contact burn cases were observed in Nagasaki and Hiroshima. These burns appeared above all where clothing fitted closely to the body--in other words, in the shoulder region, along the belts in the waist region, and also in the thigh and knee region--and it was caused by contact with hot fabric.

4.3.2.2. Secondary Burns

Secondary burns after a nuclear detonation can be a consequence of fires caused by light radiation as well as those fires which are due to the destructive effect of the blast wave.

Such burns due to hot liquids, water vapor, heated or burning wreckage, building or forest fires or ignited clothing increase in importance above all in

cities or heavily built-up regions and in forests as well as in those persons who are in destroyed vehicles. But because they do not reveal any peculiarities compared to the ordinary burns, we will not make any further statements on this score.

The permanent organization and implementation of fire protection, a rapid and comprehehsive situation estimate after enemy nuclear strikes, and the immediate initiation of full-oriented and resolute action are of great importance to the prevention or maximum reduction of troop casualties due to secondary burns.

In this connection, the morale factor--especially the steadfastness of the troops--will play an important role so that it will be possible also in complicated situations quickly to overcome moments of anxiety and to prevent the development of panic situations at the right time.

Regarding the required protective measures during unit operations in areas in which large fires were caused by nuclear detonations, there is a large number of analogies to the problem complex of protecting troops against enemy incendiary substances. Some of these questions will be touched on later.

An important prerequisite already consists in the correct selection of shelter and operational areas for the troops and the early recognition of particularly endangered directions and areas. This leads to such measures as the removal of all easily combustible materials, the allocation of manpower and resources for firefighting, the guarantee of freedom of maneuver, maximum use of existing shelter facilities, and the exploitation of the terrain's natural protective qualities.

At first there will only be some individual fire foci after a nuclear detonation but later on they might merge into contiguous fire areas; the evaluation of the anticipated influence of the fires on further unit operations is therefore a matter of primary concern.

Firefighting and the evacuation of troops from the centers of area fires must be started immediately. Available manpower and resources must be employed for this purpose in a concentrated manner.

To put out fires in shelters, combat vehicles, etc., the sources of fire must be covered with sand, small fires must be prevented from spreading further and must be restricted as much as possible by tearing down camouflage nets, overhead covers, canvas, and other items.

Burning clothing must be taken off; an attempt must be made to beat the flames out or to stifle them by rolling on the ground. This absolutely requires immediate self-aid and mutual aid. All of this is unthinkable without a correspondingly high training level.

4.3.2.3. Heat Stroke

Heat stroke (hyperthermia) can play a certain role in judging possible losses after a nuclear detonation if vast area fires develop subsequently. This problem complex also has a certain significance in conjunction with the elimination of the consequences, the execution of rescue and recovery activities, etc.

Unit operations under these conditions are characterized by partly extraordinarily high outside temperatures and heavy physical and psychological stresses, further increased by the need for partly working while wearing protective clothing. Here there can be a disturbance of the organism's heat regulation and there can be temperature rises to as much as 42-45° C.

The first signs of heat stroke are headaches, dizziness, and a feeling of weakness, as well as an inclination toward fainting. One thing that is particularly dangerous is the restriction of the element of resolute action caused by brain edema and this of course can prevent people from saving themselves.

This is why first-aid measures must be carried out at the right time (opening all tight clothing pieces, administering cold drinks if the person is conscious, and others). Otherwise there will be hallucinations, twilight states, and spasms. Respiratory paralysis and cardiovascular failure finally can bring about death.

Commanders must restrict the need for wearing protective gear--especially at extremely high outside temperatures--to the possible minimum, they must organize the necessary relief or shift work, and they must see to it that persons suffering from heat stroke will quickly be evacuated from areas endangered by fires.

4.3.2.4. Blinding

Possible damage to the eyes due to light radiation from a nuclear detonation will depend extensively on the magnitude of the light impulses appearing at the particular distances (although with restrictions), the spectral makeup of radiation, the action conditions, and the optical qualities of the eyes.

In contrast to primary burns, there are however some special aspects here regarding the action mechanism of light radiation.

The fireball from a nuclear detonation is about 100 times brighter than the sun in its early stage. The intensity of light radiation emitted by it is extraordinarily high. The biggest damage factor regarding the eyes consists of the visible and IR portions of light radiation which in individual cases can lead to brief blinding, to temporary loss of night-time accomodation, and to retina burns.

Concerning the effect of light radiation on the eyes, there is in most cases only a temporary blinding if the person involved did not happen to be looking

directly at the fireball at the moment of detonation. The duration of this blinding in general is no more than 2 min during the day and about 3-5 min at night, depending on the detonation intensity and the distance from the detonation center.

When a person happens to be looking at ground zero of the detonation (not into the fireball) at night, the period of blinding can be something like 10 min. Moreover, one must expect a loss of night-time accomodation lasting 20-30 min.

According to data from various American and Japanese authors, the duration of blinding in Hiroshima (clear, bright summer day) generally was up to 5 min and in some individual cases up to 2-3 hours. But these figures were obtained only in response to questions.[16]

Under identical conditions it is assumed for the case of cities that up to 10 percent of the injuries will be eye injuries to light radiation. In each specific situation, the duration of temporary blinding will be determined by the relative brightness existing prior to the detonation. During night-time American nuclear detonations, enlisted men and officers, who did not close their eyes at the moment of detonation, were blinded for 30 min up to distance of 8 km, regardless of the direction in which they happened to be looking, or they lost their night-time accomodation for this period of time. Longer-lasting blinding occurred only if the person was looking directly at the detonation at a range of 8-16 km from ground zero.

According to descriptions from various observers, who were temporarily blinded during nuclear detonations, one first of all perceives a glaring white, blinding light. As a result of that, there is complete blindness for several minutes. After that, persons or objects are perceived as white shadows. Color perception is disturbed for hours in case of severe blinding. Normal vision is gradually restored only after that.[17]

The distances, at which such blinding can take place, will depend greatly on the weather conditions and can be given only by way of guidance. In terms of standard values one can say that, at night, the distances at which there is significant blinding can be as much as 50 km in case of clear visibility with detonation intensities in the kiloton range and up to 10 km in case of hazy visibility. In the megaton range on the other hand we can expect blinding up to distances up to 100 km and more.

Summarizing we can say, regarding the statistics given here, that deviations of 100 percent are entirely possible as a function of the particular specific conditions.

It must furthermore be noted by way of restriction that one cannot work with the figures given in case of high-altitude detonations. Here the geographic visual range must be considered as the boundary distance.

The visible share of light radiation however can lead not only to the briefly explained temporary blinding but can also produce retina burns and thus can cause lasting eye damage.

The retina burn specifically depends on the pupil opening, the magnitude of the light impulse hitting the retina and its spectral composition, the angle of vision of the surface of the retina picture, the distance from the detonation center, and the weather conditions.

Such damage can be expected particularly at night if the person involved looks directly into the fireball and if the latter is thus reproduced on the retina. These retina burns are painless, they are connected with the formation of "blind" spots and they can extend all the way to complete blindness.

The eye's lens system focuses the incident light rays so that the fireball is reproduced on the retina. The magnitude of this reproduction will depend on the size of the fireball and its distance. At double the distance, the eye, at identical pupil aperture, would be hit only by 1/4 of the light quantity of the unit distance. In this case however the reproduction would only be one-quarter the size of what it is at unit distance; this is why the energy absorbed per surface unit of the retina in the area of fireball reproduction is practically the same at distances at which one can in a first approximation neglect the weakening of light radiation due to atmospheric absorption and scatter. This explains the great distances up to which such retina burns are possible.

Table 4.9, based on burns, presents the distances calculated for possible retina burns in the human eye for a 20 kt detonation in the air layer near the ground.[18]

Table 4.9. Radii of Zones in Which Retina Burns Are Possible after 20-kt Detonations in Atmospheric Layer Near the Ground[1]

	1 Zustand der Atmosphäre 2	Sichtweite km 3	Radien der Zonen der Schädigung km	
		4	am Tage 5	nachts
6	reine Luft (außerhalb von Städten)	40	60	65
7	Luft mittlerer Reinheit	20	25	32
8	verstaubte Luft (innerhalb großer Städte)	10	12	16
9	Dunst	3 ··· 4	5	6

Key: 1--State of atmosphere; 2--Visibility range; 3--Radii of damaged zone; 4--Daytime; 5--Night-time; 6--Clean air (outside cities); 7--Medium-purity air; 8--Dust-containing air (inside big cities); 9--Haze. (1) The values were lightly rounded.

Just how great the danger is to those persons who, at the very first moment of the detonation, look directly into the fireball, is indicated by the fact that, for example, the pupil is wide open at night and allows about 50 times more light into the eye than during the day.

At the moment of detonation there is practically no reflex and no voluntary action that would be fast enough basically to prevent eye injury. The pupil

and blinking reflexes are too slow for that but naturally do reduce the entry of light energy after 0.1 sec.

Further direct damage to the individual parts of the eye, in addition to the retina burns briefly outlined here, also depend on the wave length of the light radiation. IR radiation for the most part reaches the retina and here boosts the effect of visible light and a smaller part is absorbed by refracting media (cornea, aqueous humor, lens, and vitreous body) and can cause cornea damage and lens clouding.

IV radiation damages the cornea, the iris, and the lens by which it is absorbed.

Protection against the blinding effects of a nuclear detonation is of extraordinarily great significance. In addition to the immediate physical losses due to light radiation, which are possible above all at night and in the case of troops on the move up to great distances from the detonation center, one must also figure on the corresponding psychological effects. The scared feeling following loss of vision, that is to say, fear of possible blindness can be greater than the fear of death in uninformed persons.

The most important protection against the blinding effect of light radiation is guaranteed by the sheltering of troops, using the protective qualities of the terrain and the cover possibilities provided by vehicles and technical combat equipment. Special attention must be devoted to protection against light radiation during night-time march movements due to maximum restriction of possible visibility.

If protection against blinding is neglected under these conditions, then one can expect losses of manpower and equipment, blockages of march routes, and measured delays in the course of march movements such as vehicles crash into each other or run off the road. Similar problems arise in the case of aircraft and ship's crews.

Assuming that no special eye protection means are available, protection against blinding must be guaranteed by the following measures, depending on the existing situation:

At the moment of the light flash, the eyes must be closed immediately; one must not look in the direction of the detonation.

When taking cover, the face must be inclined toward the earth or the ground.

Except for observers on duty, all personnel must stay in field fortifications (shelters) or combat vehicles.

Relief drivers, who can take the place of drivers whose vision was damaged, must wherever possible be stationed in a sheltered position for combat and transport vehicles.

Upon the flash of a nuclear detonation, vehicles must be stopped quickly but carefully.

In special situations, an eye can be closed by a flap. Here however one must keep in mind that three-dimensional vision is lost, that is to say, there will be a great danger of accidents during convoy driving.

During protection training it must be explained convincingly that the blinding effect caused by light radiation is only temporary in case of correct behavior on the battlefield. This decisively influences the actions of blinded persons after a detonation.

By using special eye protection means it is possible decisively to reduce troop casualties due to the blinding effect. The current development status of these means however on the whole is by far not yet satisfactory. They are as a rule relatively difficult to handle, they are expensive to produce, and their use is therefore confined to special areas (for example, air force).[19]

Special eye protection means must meet very stiff requirements. Their basic production can be founded on various physical and chemical processes. Development work according to the literature on the subject is essentially concentrated on protective goggles and glasses with light-sensitive lenses which increase their optical density in response to incoming strong light radiation.[20]

The main problem in the development of eye protection means or protective devices against the blinding effect from a nuclear detonation in general consists in the fact that very short closing times must be achieved. They are on the order of magnitude of 0.0001 sec. The protective devices must in fact immediately interrupt the effect of light radiation on the eyes or they must reflect radiation. This calls for electric "sensors," that is to say, an automatic closing device which will be indirectly or directly triggered by light radiation. Such protective devices can be designed not only as individual eye protection means but also as collective systems in combat vehicles, etc.

In addition to the previously mentioned extremely short closing times, there are other requirements for protective devices for eye protection means ready for use by the troops. From the theoretical viewpoint they consist essentially of the following:

They must be simple to use and they must be sufficiently light-permeable to guarantee the observation of the battle and the operation of combat vehicles and combat equipment under normal visibility conditions with the least possible restriction of the field of vision;

They must attenuate light radiation roughly by a factor of 10^6 and they must quickly again return to their initial state.[21]

Below we briefly discuss some examples of possible eye protection means. Reference is made to the literature sources given for further study.

In the case of screening glasses, transparent and nontransparent plates are used in a vertically alternately arranged pattem in place of normal eye glases; these plates can so be shifted with respect to each other in a horizontal manner that complete light-proof closing can be achieved by means of an automatic photoelectric device responding to light radiation. The plates which allow light to pass through are narrower than the pupil but they nevertheless reduce the normal incoming light quantity to about 40 percent. Because the automatic closing device responds after several hundred microseconds, about 0.01 percent of the light radiation from a nuclear detonation will still get into the eye.

In contrast to screening glasses, injection locks are primarily suitable for combat vehicles. Such protective devices (carbon injection shutter) basically consist of a cassette with two opposite transparent walls. The automatic device triggered by the flash of light ignites pyro cartridges which in turn fling a highly-dispersed graphite suspension or a darkening liquid into the free space of the cassette. According to American data, this is supposed to result in an attenuation of the incident light to 0.1 percent. This means that complete blinding protection cannot be achieved.

Other possibilities consist in the use of electro-optical locks (polarization filters, short closing times of 10^{-6} to 10^{-8} sec, use of the Kerr effect), narrow-band filters of identical optical density (filters allow only a narrow range of the total spectrum to pass through, coordination with the light frequency of fixtures, etc.), eye shields with transparent metallic coating (attenuation of light radiation to about 2 percent), or simple black glasses (ordinary sunglasses do not offer any protection).

All of the methods mentioned here still reveal considerable disadvantages at this time. The closing times are either too long or the attenuation factors are too low or the cost is extraordinarily high.

4.3.3. Effect on Towns and Woods--Conclusions for Unit Operations in Large-Area Fire Zones

The annihilating effect of light radiation due to the ignition of various materials and the start of fires must be viewed in closer conjunction with the effect of the blast wave. In this connection the reader is referred to sections 3.5.2 and 4.3.1. In the context given here we want to subject especially fire effects in cities and woods to basic investigation.

4.3.3.1. Effects of Light Radiation in Towns

In the two Japanese cities of Hiroshima and Nagasaki, the immediate effects of light radiation and the secondary fires varied greatly. The area completely destroyed by fire in Hiroshima was 11 km^2 and that was almost four times bigger than in Nagasaki.

This alone shows that the specific effects of light radiation from a nuclear detonation are determined by a series of factors and that especially the weather conditions and the terrain relief have a much greater effect on the origin and spread of fires than the blast wave because blast wave destruction in both cities differed only to a minor degree.

The main reasons for this widely varying annihilation effect deriving from light radiation are to be found in the fact that Hiroshima is located in a continuing pattern on a rather level surface in the area of the mouth of the Ota River whereas Nagasaki essentially reveals a long-drawn-out pattern along two river valleys.

Because of that, conditions differed both regarding the origin of the fires and the spread of the fires.

Light radiation magnifies the destruction caused by the blast wave in that it creates a series of fire foci over a relatively large surface area due to the ignition of easily combustible substances, such as dried and rotten wood, dry grass, leaves, and paper. Because many household articles, such as curtains and blankets, are also easily flammable, light radiation can cause fires in the buildings themselves likewise (see the figures in Table 4.6). Looking at this problem complex however one must distinguish two aspects: The origin of fire foci and the spread of the fire itself.

Concerning the origin of the fire, we still sometimes run into the mistaken opinion that light radiation, in case of corresponding weather conditions, immediately and directly leads to continuing large-area fires. But that is not so. With the exception of the immediate detonation area, the blast wave acts upon the particular objects seconds later than the light radiation. This is why we get not only shadow areas caused by hills, trees, etc., but also by the terrain itself. This means that a part of the buildings will completely or partly shield another part against direct effects. This observation applies particularly to greater ranges from the detonation center. One must furthermore keep in mind the previously mentioned fact that the blast wave will put out a part of the fires although new fires may be stirred up later on due to the smoldering remnants. One must furthermore not simply transpose the devastation caused by fire in both Japanese cities to European cities because both the building style and the building density differ greatly. This was pointed out earlier.

We explained previously that, as a result of a nuclear detonation, the direct effect of light radiation, first of all, and the indirect effect of the blast wave, second, can cause fire foci. While the estimate of the number of fire foci caused by blast wave destruction (destruction of heated stoves and boilers, containers with easily combustible or explosive liquids and gases, short-circuit of electric power lines and installations) is very difficult, we can work out some laws for the immediate effect of light radiation. The number of developing fire foci, other things being equal, will primarily depend on how fireproof the buildings and installations are and this will depend on the buildup density, that is to say, on the quantity and distribution of easily combustible substances.

The number of possible primary fire foci is determined more or less by the quantity of easily combustible material present in a certain surface area while the distribution of these substances permits conclusions as to the spread of the fire and thus the possible merger of individual fires into area fires.

In this connection we must consider the magnitude of the light impulses required for the ignition of easily flammable materials. From the numerical data in Table 4.6 we can tell that, out in the open, especially dry and rotten wood, grass, and foliage will be sources of primary fires. Naturally the necessary ignition temperature and thus also the required light impulse will in each case depend on the thickness and moisture. Thick and moist materials are frequently carbonized along the surface, without the ignition temperature being reached.

Experience shows that, during dry seasons, one must figure on the development of primary fire foci out in the open (grass and underbrush fires) if the magnitude of the light impulses is between 5 and 10 cal cm^{-2}.

As we can further see from Table 4.6, one can expect fires in residential buildings after light impulses of 4-7 cal cm^{-2}. With the help of these values one can at least roughly estimate the radii of primary fires originating in cities and towns.

Naturally, one must always clearly realize the limitations of such considerations.

Table 4.10. Guidance Values for Radii of Possible Primary Fires in Cities (Average Visibility Conditions, Dry Weather)

Detonation intensity kt	Radius m
1	500
10	1500
100	4000
1000	10000
10000	30000

After light radiation has caused local fire foci in various places, it will depend on the type of construction and the buildup density, the terrain vegetation cover, and the weather conditions as to exactly how the fires develop further. The character and the extent of blast wave destruction will also greatly influence this.

On the one hand, the destruction of partition walls, doors, windows, etc., create favorable conditions for the spread of the fire. On the other hand, the wreckage masses of collapsed buildings can slow down the spread of the fire. This applies above all to the zone of heavy to medium destruction.

In cities therefore the main fire zone would seem to lie in the area of medium to heavy blast wave destruction, where the buildings are still heavily hit although they will not completely collapse as far as their bulk is concerned.

The type of buildup and the buildup density are extraordinarily differentiated in various cities and towns. This is why in the context given here it will be impossible to present any more detailed investigations. Generalizing we might observe that the ratio between the mass of combustible and noncombustible substances under European conditions in residential buildings will be 1:10. But a by far more favorable ratio can be achieved through preventive fire protection measures.

The less the buildup density is, other things being equal, the smaller will be the possibility of the fire spreading from one burning building to another. Table 4.11 illustrates this situation.

Table 4.11. Guidance Values for the Dependence of Fire Spread on Buildup Density

Interval between buildings m	20	30	60	80	100
Probability of fire spreading %	40	15	8	5	1

Regardless of these numerical values one must however consider the possibility that the blast wave might carry burning materials over larger intervals or clearings and might thus cause new fire foci.

To prepare a situation estimate on the fires after enemy nuclear strikes against cities it is a good idea to distinguish between individual, mass, and area fires. Firestorms can be considered a special type of area fire.[23]

We speak of mass fires if more than 25 percent of all buildings still preserved or partly destroyed by the blast wave are engulfed by fires. If more than 90 percent of all of these buildings are so engulfed, then we have an area fire.

In European-style cities, with mostly low stone houses, one must figure on the possible development of area fires if the buildup density is more than 20 percent. In case of modern city sections (large-block construction style), that would seem to be the case only if the buildup density is more than 30 percent.

In conclusion we might make some remarks on the origin of firestorms. Firestorms are known from World War II, for example, from Dresden and Hamburg. They originated due to large-area and dense bombing raids using incendiary bombs. In Hiroshima, a firestorm resulted from the nuclear detonation whereas there was no firestorm in Nagasaki. The firestorm in Hiroshima developed about 20 min after the detonation. The wind blew from all sides toward the burning city sections; 2-3 hours after the detonation, maximum wind velocities of 50-60 km/hr^{-1} were reached. Rain fell at the same time.

The firestorm destroyed all buildings on the burning surface. Stone houses, only partly destroyed by the blast wave, were also burned out. On the other hand, the firestorm prevented the fire from spreading to the outside.

In Nagasaki, the wind originally blew in the direction in which there was only little combustible material. Besides, the flames found little to feed on in the valleys.

Summarizing all of the known facts, we can conclude that, under the conditions of a pronounced brick or large-block construction style, the development of firestorms as a consequence of nuclear detonations is unlikely but not impossible.

A necessary and possible firefighting measure after nuclear strikes in cities can be extraordinarily complicated. The practical and concentrated use of available manpower and resources above all presupposes exact fire reconnaissance. The main effort in firefighting must be aimed at those areas or objects in which there are larger groups of people in shelters which may be partly or completely buried.

Getting at the fire foci can be made difficult by vast blockages as well as intensive heat and smoke development.

In determining the sequence of rescue and recovery activities to be carried out, one must absolutely take into account the further propagation direction of the fires, considering the existing weather conditions. It is first of all necessary to continue to fight fires which make rescue and recovery activities difficult or impossible. One must absolutely prevent manpower and equipment from being trapped by developing area fires. Troops located in areas with mass fires and obviously unable effectively to fight those fires must be evacuated at the right time.

In conclusion it might be observed that special mask filters are needed to provide protection against possible carbon monoxide poisoning.

4.3.3.2. Effects of Light Radiation in Woods

Nuclear detonations near or in and over forest massifs can lead to very intensive and large-area forest fires. In conjunction with vast forest destruction due to the blast wave (see Section 3.5.2.2), this leads to considerable effects on unit operations in the areas immediately involved and in the direction of propagation of the fires.

An analysis of the literature published so far on this problem complex clearly brings out the great difficulties connected with an exact evaluation of these questions after nuclear detonations. The causes of this are to be found in the complex effect of a large number of influencing magnitudes which decisively determine the probability of the development of primary fire foci in woods as a result of a nuclear detonation and the extensive absence of generalizable numerical values deriving from test detonations. The situation is somewhat different with respect to the spread of the fire although here again it is impossible simply to transpose the results of "conventional" forest fires. First of all, after a nuclear weapon detonation, primary fire foci will spring up simultaneously over a large area. This area, for example, at a nuclear detonation with an intensity of 20 kt, in dry weather and mid-summer temperatures, will be as much as 15 km^2 larger.

In addition there are vast "windbreak zones" which not only produce entirely different conditions for the propagation of fires but which also cause additional difficulties for unit operations and further restrict the possibilities of effective fire fighting.

Light radiation from a nuclear detonation generates primary fire foci due to the ignition of easily combustible materials on the forest soil and sets fire to tree tops, especially in evergreen forests. Accordingly, soil fires (light impulse of 3-5 cal/cm^{-2}) and treetop fires (5-10 cal/cm^{-2}) will arise after a nuclear detonation.

Because the light radiation falling on the forest soil as a rule is greatly attenuated by the trees themselves (average attenuation factor 0.3-0.5) and because the angle of incidence of light radiation grows as the distance grows, we can say that soil fires are characteristic of the immediate detonation area while treetop fires will be characteristic of greater distances from the detonation area. This kind of estimate also springs from the fact that the blast wave in particular will again "put out" most of the treetop fires in the immediate detonation area.

In the area, in which vast "windbreak destruction" and primary fires are simultaneously superposed, far-flung total fires--which will cover the entire height of the trees-can develop very quickly after the detonation.

Table 4.12 gives some guidance values for the size of areas on which primary forest fires can develop as a function of the detonation intensity under conditions favorable for the development of fires.

Table 4.12. Guidance Values for Zones of Possible Fire Development in Forests (Dry Weather, Summertime Conditions)

Detonation intensity kt	Radius of possible fire zone m
1	500
10	1500
100	5000
1000	15000
10000	40000

The areas shown here must be considered to be maximum values although considerable deviations are possible from them, depending upon the specific conditions.

The following factors play a role here: The character of the forest substance as such, the season, the weather conditions, temperature, relative air humidity, wind velocity, and the terrain relief.

Regarding the character of the forest fire, one must differentiate further on the basis of closer examination. In deciduous woods, the danger of fires developing there is not as great as in evergreen forests, above all in fir forests. In evergreen forests one must expect the rapid spread of treetop fires and soil fires due to the ignition of the layer of scattered needles, dry brushwood, and dried-out tree bark fragments. A tall forest is generally less threatened than a young forest. In tall forests, especially in deciduous forests, soil fires will spread relatively slowly up to the crowns of the trees.

Table 4.13 presents an overview of the ignitability and combustibility of the most important forest inventory forms. In addition to generally known pertinent relationships, which will not be explained here in detail, we might remark once again that the ignitability of the forest generally is greatest during the months of March and April and that the fire's spreadability is greatest in July and August.

The effect of weather conditions is manifold. But the relative air humidity plays the greatest role in the origin of primary fire foci. The lower the relative air humidity, the greater will be the ignitability of combustible materials and thus the danger of fires.[25]

Table 4.13. Ignitability and Combustibility of the Most Important Forest Inventory Forms[24]

Ignition and Fire highly improbable	Old deciduous high forest without soil flora in summer foliage; old evergreen wood with compact, dense deciduous tree undergrowth and summer foliage; wet-soil flood plain and broken alder forest; compact evergreen pole wood without soil flora, brushwood or peat layer with advanced branch clearing high above soil
Easily ignited but little intensive fire, as a rule moving rapidly as soil fire	Low forest, spring condition, no foliage; wild-growing, above all grass-covered deciduous and evergreen woods in spring
Difficult to ignite but burning as full-scale fire, difficult to extinguish, after ignition, severe heat development, moving slowly	Compact pure evergreen thickets and pole woods before start of branch clearing; ground-level or two-level evergreen stands with undergrowth of evergreen wood or old evergreen wood with heavy juniper undergrowth
Easily ignited and as a rule difficult to extinguish full-scale fire, burning with tremendous heat generation, running fast	Evergreen scrub woods wildly overgrown with heather or grass, for example, woods owned by farmers; evergreen plantations with grass or heather as soil flora prior to complete growth; tree-cutting areas with dry cut trees; heath areas of all kinds.

Concerning the spread of fires, we will briefly indicate below only a few aspects by way of guidance. Otherwise reference is made to the numerous items in specialized literature.[26]

In keeping with their character, we distinguish the following in forest fires:

Soil [bottom] of running fires,

Treetop or crown fires and

Total or full-scale fires.[27]

The growth of the fire surface in these fires, other things being equal, depends on the terrain relief and is roughly proportional to the square of the wind velocity.

The speed with which soil [bottom] fires spread differs greatly. In fires involving waste materials on the ground or peat, the spread of the fire is very slow (< 100 m/hr^{-1}); in the case of dry grass or heath, the propagation speed in the direction of the wind can be as much as 25 km/hr^{-1}. In addition we have the fact that numerous primary fires, simultaneously distributed over a larger area, are bound to spring up as a result of nuclear detonations.

In treetop fires one observes relatively fast fire propagation speeds (up to 10 km/hr^{-1}). Total fires cover the entire height of the forest and are connected with particularly severe heat generation. They attain average propagation speeds of up to 2 km/hr^{-1}. Table 4.14 presents an overview of the ratio between the width and length of fire propagation.

Table 4.14. Ratio between Width and Length of Forest Fires as a Function of Wind Conditions[28]

Wind condition	Ratio between width and length
No wind	1:1
Slight wind	1:1.7
Moderate wind	1:2.7
Strong wind	1:3.5
Storm	1:4

Fighting the large-area fires possible after nuclear detonations is an extraordinarily complicated process. The previously mentioned blockages resulting from blast wave destruction can have a further aggravating effect. But corresponding radioactive contamination due to radioactive detonation products and severe smoke development must also be considered.

This is why, in addition to all other necessary firefighting measures, one must devote particularly great attention to the evaluation of the terrain sectors or areas which, in keeping with their natural condition, offer favorable prerequisites for the further prevention of fire propagation (areas without woods, deciduous forest without combustible soil cover, water surfaces, etc.). Furthermore, fire breaks must be made where possible; they should be

at least two tree lengths wide. The interval between two fire break strips should be no more than 2-4 km.

But one must not overestimate the effect of such obstacles (blocks). For example, Bauer very emphatically points out that blocking strips with a width of 250 m can be easily jumped after the fire has been developed fully in large-area forest fires.[29] This undoubtedly means that the particular manpower and equipment available under such conditions must be employed in a concentrated manner to fight the fires in the most important sectors or directions.

Firefighting in the immediate operations or assembly area of military units must begin immediately after a detonation. All available resources, especially Engineer equipment, must be used for this purpose. Underbrush fires can be fought by piling on dirt, with water, or also with chemical firefighting solutions. The decontamination vehicles are suitable for this among other things. Making a backfire or blasting clearings are other possible steps here. Considering the relationships already explained in Section 4.3.3.1, it is likewise true in fighting forest fires that only a rapid and comprehensive situation estimate can prevent major losses and can guarantee the accomplishment of combat missions.

4.3.3.3. Unit Operations under Area Fire Conditions

From what we have said so far it emerges that area fires are possible after nuclear detonations in towns, woods, and prairies (cultivated prairies). Because of the great significance of such fires, we will below discuss some additional basic problems.

By area fires we mean those fires whose dimensions come close to or exceed the width or depth of the combat deployment of military units and which restrict the operational freedom of units in terms of time and space due to high temperatures, severely limited visibility, and the irritant effect.[30]

According to Brabovoy, area fires can be expected with propagation speeds of up to 1,000 m/hr^{-1} already 30 min after the start of the fires under unfavorable conditions in towns where half-timbered and wooden buildings prevail. In towns with multistory stone buildings, one can expect area fires 2-3 hrs after the detonation with propagation speed of 50-100 m/hr^{-1}.[31]

Such generalizable statistics are presently not available for forests.

Unit operations in area fire regions or the passage of such areas can be connected with great difficulties. In addition to the possibility of the direct effect of the fire on combat vehicles and combat equipment, heat radiation and smoke development play a big role here. Under these conditions even night-time vision instruments can be ineffective. Well-developed area fires in cities with a high buildup density and narrow streets are in fact impassable. The same applies to woods in which total fires have developed.

On the other hand, the fronts of weak and medium soil fires in woods and prairies, on clearings and trails as a rule can be directly negotiated with combat vehicles and transport equipment. To prepare a situation estimate of the particular specific fire situation, commanders and staff need comprehensive information or reconnaissance data which must be constantly updated. A situation estimate is possible only with the help of tables or analytical calculations.

The following must be evaluated specifically:

The extent of the area fire, its intensity and the direction and speed of fire propagation;

The size and location of areas in which one must expect certain visibility interference and heavy smoke generation;

The physical and psychological strength of personnel as well as the degree of protection for combat vehicles, etc., against the direct effects of the fire.

As a result of this situation estimate, considering the combat assignments given and enemy operations, a decision may be made to go through the area fire or to go around it. This also includes the calculation of the manpower and equipment necessary to guarantee these measures as well as the preparation of the troops themselves.

The following methods are possible specifically:

Going around the fire in front of the fire front;

Going around the fire behind the front of the fire;

Going through the fire front from the move;

Going through the fire front using lanes;

Waiting until the fire dies down.[32]

Each of the methods mentioned has its advantages and disadvantages and is connected with a certain degree of danger to the troops. Regardless of that, one can consider going around fires in front of the fire front as the best alternative because the troops in this case will not have any direct contact with the fire and because a compact march movement is possible also with combat and transport vehicles of differing resistance.

A decision to go through a fire front from the move is a good idea only if we are dealing with an area fire of low intensity and if the maneuver possibilities are good. In conclusion, Table 4.15 presents some features needed in judging the type and intensity of a forest fire.

Table 4.15. Characteristics for the Determination of Forest Fire Types and Intensities

Color of smoke	Character of convection column	Movement of smoke in convection column
White or bright-grey	No columns; above the fire, a smoke cloud in the shape of cupolas or waves	In case of weak wind, the smoke cloud rises and its overall shape looks like a smoke column
Bright-grey, black in the cupolas over the front	No column; smoke cloud over fire, individual convection columns developing over the front	Pulsating development of black smoke cupolas
Black smoke cupolas	Convection cloud springs from smoke cupolas over the front	Column inclined at wind velocities of more than 3 m/sec^{-1}
Black	Convection column is well developed and reaches altitude of 600-1,000 m; sharp angle at higher altitudes due to sudden periodic increase in wind velocity	Thick, periodically pulsating cupolas
Black	Convection column well developed up to altitude 2,000 m and more; sometimes mushroom-shaped	Rolling smoke clouds and cupolas over the entire height of the column, smoke often moving in spiral pattern in column

[Table 4.15 continued] In Terms of the Shape of the Smoke Cloud and the Convection Column[33]

Type of fire	Intensity of fire	Possible character of further development of fire
Soil [ground] fire	Weak	Increase not to be expected
Soil fire	Medium intensity	Increase in fire intensity possible; expect flying sparks
Soil fire	Strong	Increase in fire intensity possible; column inclined, expect flying sparks over significant distances
Total fire, slow-running	Weak	Fire develops due to suction in convection column at wind velocity of up to 3 m/sec^{-1}; at wind velocities of 4-5 m/sec^{-1}, the convection column is inclined; flying sparks possible over long distance
Total fire, slow-running	Medium intensity	Flying sparks to be expected over distances of up to 4 km
Total fire, fast-running	Weak	

4.3.4. Protective Qualities of Field Fortifications and Shelters

Light radiation from a nuclear weapon detonation does not represent a direct main annihilation factor with respect to field fortifications. Instead, its effect as a rule recedes considerably in relation to the blast wave. In connection with this kind of estimate one must however judge the terrain in which these installations are located.

In heavily built-up regions and in woods there is the danger that the development of area fires might some time after the detonation reach field fortification or shelter areas or sectors and that personnel might be forced to leave those facilities due to severe heat and smoke generation.

Similar effect can result from vast grass and prairie fires. But we can estimate here that, because of the "extinguishing" effect of the blast wave, the main fire zone will be outside the blast wave destruction range. This is why one may expect that conditions will be favorable here for subsequent fast and successful firefighting.

Even if one assumes that one cannot basically get along without using wood in the construction of field fortifications and special shelters, this need not necessarily produce any great danger of fires. For example, the data in Table 4.6 reveal only a low degree of ignitability even for dry wood. Of course, beyond this it is necessary to organize all fire protection measures possible under the particular situational conditions and to implement such measures to increase resistance against the start of fires.

This includes the following:

The impregnation of combustible structural elements with fire-retardant means (that could include such chemical compounds as ammonium carbonate, ammonium chloride, magnesium chloride, aluminum sulfate, etc., or expedients, such as wet clay, lime paste);

Equipping bunkers and shelters with tightly-closing, incombustible doors;

Using structurally difficult-to-burn camouflage equipment;

Removing all easily combustible materials from the vicinity of installations and correct storage of explosives, fuels, and lubricants;

Providing firefighting equipment for particularly important installations and putting up fire protection strips along the entrances to shelters or in trench supports.

Under these conditions, unit field fortifications offer reliable protection against the annihilating effects of light radiation.

4.3.5. Effect on Combat Vehicles and Equipment and Their Protective Qualities

The possibilities of direct destruction of and damage to combat vehicles and equipment due to light radiation are manifold and differentiated. They can consist in the fact that easily combustible materials are ignited and cause fires in cabins and combat compartments, that surfaces or coats of paint will be carbonized or burned, that fuel tanks explode, and many other things.

Basically, these possible effects of light radiation however are of concern only at those distances at which the objects observed can withstand the effect of the blast wave without any essential damage. An analysis of this problem complex shows that the blast wave represents the main annihilation factor for nuclear weapon detonations in the lower kiloton range also for combat vehicles and most of the combat equipment. Armored combat vehicles, that is to say, tanks, APC's, armored prime movers, etc., offer the best protection against light radiation.

Due to the increased use of heat-resistant materials, impregnation of textile fabrics, the use of flame-resistant or flame-retardant paints, etc., it has however generally been possible to improve protection against the annihilation factor of light radiation also in unarmored combat vehicles, transport equipment, and combat equipment. Nevertheless, we still have a series of easily flammable substances and materials, for example in motor vehicles.

This for example includes canvas covers, cushions, and blankets. For example, cushions and seats can be ignited at light impulses of 15 cal/cm^{-2}, cloth covers will ignite at 6 cal/cm^{-2} and canvas covers will ignite at 10 cal/cm^{-2}. In many cases, remnants of diesel fuel, oil-contaminated rags, fuel tanks or cans can cause primary fires. This is why order and cleanliness are part of the basic prerequisites of fire protection.

The following additional measures are necessary:

Providing vehicles with firefighting equipment;

Parking vehicles in a protected position in shelter pits;

Use of fire-proof canvas, covers, and casings;

Supply and use of locally available firefighting equipment and others.

When combat vehicles catch fire, it is first of all necessary to fight fires on fuel tanks, in the engine compartment, and along the tires. The cargo of the vehicles must also be taken into consideration. In case of fires on artillery weapons, it is in particular necessary to extinguish fire on optical instruments and tires. Ammunition located in areas endangered by fire must immediately be covered with a layer of dirt before a direct danger of explosion can arise.

Review Questions

4.12. What are the factors influencing the way in which light radiation affects a body?

4.13. Explain the meaning of the heat impulse.

4.14. Why are theoretical computations of the temperature and thermal behavior of various bodies regarding light radiation connected with great difficulties?

4.15. What do we mean by the critical light impulse?

4.16. What are the forms of effect of light radiation on the human organism against which the troops must protect themselves?

4.17. Explain the concepts of primary and secondary burns, profile burns, and contact burns. Derive the necessary and possible protective measures.

4.18. What is the influence of the type of clothing (of the uniform) on the character of possible fire injuries?

4.19. Through what measures can unit casualties due to heat stroke be prevented or reduced?

4.20. Why is the protection of troops against the blinding effect of a nuclear weapon detonation so important?

4.21. What does the severe physical and psychological stress on blinded individuals result from?

4.22. What measures can reduce the danger of blinding under combat conditions?

4.23. Classify the fires possible in cities and forests as a result of a nuclear weapon detonation.

4.24. What are the factors on which the danger of fires in towns depends?

4.25. What reciprocal relationship exists between the blast wave and the origin or spread of fires?

4.26. Explain the basic principles of firefighting in towns.

4.27. What is the effect of light radiation on woods? Under what conditions must one expect area fires?

4.28. Explain the content and scope of necessary fire protection measures during unit combat operations in forest regions.

4.29. What methods of going through or going around area fires are feasible under which situational conditions?

4.30. What are the protective properties of field fortifications and combat vehicles with respect to the annihilating effect of light radiation? Through what measures can their degree of protection be considerably improved?

4.31. Compare the annihilating effects of the blast wave and light radiation, using selected examples. Summarize the resultant measures of protection against nuclear weapons.

4.4. Notes for Chapter 4

1. See also DV-66/3, MfNV, 1963, p 222.

2. For the definition of the black body, see among others Recknagel, A., "Physik," Volume of Optics, VEB Publishing House, Technik, Berlin, 1962, pp 122 ff. and 273 ff.

3. See also DV-66/3, loc. cit., p 249 f.

4. In working with the analogous illustrations in DV-66/3, p 235, one must keep in mind that the detonation altitude is given in kilometers there.

5. See also Feller, M., MILITAERTECHNIK, 6, 1966, 6 pp 213-216.

6. The illustration showing how this works was copied from "The Effects of Nuclear Weapons," Washington, 1962; Russian edition of the above-mentioned work obtainable from the USSR Defense Ministry Publishing House, Moscow, 1965, p 350.

7. The nomogram was taken from Feller, M., loc. cit., p 216.

8. Klose, K., and H. Hartmann, "Der Einsatz von Nebelmitteln" [Use of Smokescreens], German Military Publishing House, Berlin, 1954, pp 177ff.

9. The units of measure used, to the extent that they are defined, correspond to the Decree of 31 May 1967 on physical-technical units (GBL. II, p 351). See also among others Padelt, Laporte, "Einheiten und Groessenarten der Naturwissenschaften" [Units and Types of Magnitudes in the Natural Sciences], VEB Technical Book Publishing House, Leipzig, 1967. But the dimensions were adapted to a series of units relating to the specifics of the subject treated here. This must be kept in mind when one must work with data taken from tables presented in other works.

10. See also Feller, M., loc. cit., p 213.

11. In this connection, see Bendel, F., and K. Langhans, "The Effective Light Impulse from Nuclear Weapon Detonations," MILITAERTECHNIK, 1, 1961, 2, pp 41-43; Feller, M., "Critical Comments on the Use of the Effective Light Impulse for the Computation of Nuclear Weapon Detonation Effects," MILITAERTECHNIK, 6, 1966, 6, pp 213-216.

12. On this problem complex, see Ponikarov, N., and others, "What One Must Absolutely Know about Nuclear Weapons and Defense against them," ATOMIZDAT Publishing House, 1965, Russian.

13. The photo was taken from "The Effects of Nuclear Weapons," loc. cit., p 544.

14. Ibid., p 544.

15. Ibid., p 545.

16. "Medical Questions of Atomic Defense," Inlitizdat Publishing House, 1955, Russian (collection of articles from American, British, French, and Belgian periodicals).

17. On these problems, see Feller, H., "The Effect of Light Radiation from a Nuclear Weapon Detonation on the Human Eye," ZSCHR. MIL.-MED. [Military-Medical Periodical], Berlin, 6, 1965, 2, p 79; Rohrschneider, W., and M. Hinterthaner, "Eye Damage Due to Atomic Explosions," MUENCHENER MEDIZINISCHE WOCHENSCHRIFT [Munich Medical Weekly], 102, 1960, 22.

18. Byrnes, V. A., and others, "Chorioretinal Burns Produced by Atomic Flash," J. AM. MED. ASSOC., 168, 1958, 11 October, p 778.

19. Britten, J., "Apparatuses for the Protection of the Eyes," ORDNANCE, 1964, November-December, p 312; anonymous, "Eye Protection against Atomic Flashes," KERNWAFFENDETONATIONEN [Defense and Science], Bamberg, 9, 1965, 3, p IV.

20. Zherazhov, S. G., "Blinding and Retinal Burns after Nuclear Weapon Detonations," VOYENNO-MED. ZH. [Military-Medical Journal], Moscow, 1964, 10, p 23.

21. Ebeling, D., "Protection against Blinding from Atomic Explosions," ZIVILVERTEIDIGUNG [Civil Defense], Ban Honnef, 34, 1970, 5, p 35.

22. Photos 4.15 to 4.19 were taken from "The Effects of Nuclear Weapons," loc. cit., pp 314-327.

23. See also Tsivilyev, M. P., and others, "Engineer Operations in the Action Focus of a Nuclear Strike," USSR Defense Ministry Publishing House, Moscow, 1968, p 22, Russian.

24. The table was completely taken over from Weck, J., "Waldbrand, seine Vorbeugung und Bekaempfung" [Forest Fires--Prevention and Control], Series of technical books on fire protection, Stuttgart-Cologne, 1950, p 37.

25. See also among others Martin, B., MILITAERWESEN, 11, 1967, 4, pp 535-544.

26. Concerning the prediction of forest fires in combat, see also Bauer, E., MILITAERWESEN, 12, 1968, 5, pp 653-663

27. It must be pointed out here that we refrain from using the term "fire" for the sake of uniform military terminology.

28. Ibid., p 660.

29. Ibid., p 661.

30. Martin, B., "Operations during Area Fires," MILITAERWESEN, 15, 1971, 1, p 80.

31. Grabovoy, I. D., "Unit Operations under Conditions of Area Fires," USSR Defense Ministry Publishing House, Moscow, 1969, p 26, Russian.

32. Detailed explanations on this problem complex can be found among others in Martin, B., "Operations during Area Fires," loc. cit. pp 85 ff.

33. The table was completely taken over from Grabovoy, I. D., "Unit Operations under Conditions of Area Fires," loc. cit., p 57.

5. Instantaneous Nuclear Radiation from Nuclear Weapon Detonation

5.1. General Description of Instantaneous Nuclear Radiation

In the process and as a result of a nuclear weapon detonation, the developing radioactive detonation products emit various types of nuclear radiation. This includes gamma radiation, neutron, beta, and alpha radiation.

In order to describe the essence of this nuclear radiation better and in order to be able logically and clearly to analyze and describe the individual processes and phenomena, we distinguish here between instantaneous nuclear radiation and residual nuclear radiation which appear as additional annihilation factors in addition to the blast wave and light radiation deriving from a nuclear weapon detonation.

This kind of subdivision is practical not only for methodological reasons. One must also keep in mind the circumstance that even at very great detonation intensities the radioactive cloud will, at the very latest, one minute after detonation, have reached such an altitude that the nuclear radiation springing from it can no longer be directly effective on the earth's surface. Instantaneous nuclear radiation from a nuclear weapon detonation in the dense atmosphere essentially consists of electromagnetic gamma radiation and corpuscular neutron radition. Its action duration is defined for a span of time up to 1 minute after detonation. The neutron radiation emitted after that is included among residual nuclear radiation.

Instantaneous nuclear radiation sometimes is referred to in the literature also as ionizing or penetrating radiation. This describes both of its most essential properties.

5.1.1. Some Basic Concepts and Units of Measure of Gamma and Neutron Radiation

To understand what follows, we must briefly summarize some basic concepts and units of measure of nuclear radiation. In this connection we must emphatically

point out that the international studies on the final determination of basic units of nuclear radiation have not yet been completed at this time.

This is why we will in the following particularly take into consideration the specifics of nuclear radiation after nuclear weapon detonations. Because agreement must be achieved with the applicable service regulations, the symbols and terminology customary in military practice must also be extensively retained, even when there are deviations under certain circumstances from corresponding general legal determinations. Reference will be made to this problem complex in places where this is necessary. Newly proposed symbols are sometimes shown in parentheses.[1]

5.1.1.1. The Ion Dose (Exposure)

A nuclear weapon detonation releases gamma radiation and neutron radiation of varying energy. If any body whatsoever is hit by this nuclear radiation, the latter transmits a portion of its energy to the irradiated substance [material]. This energy transfer takes place mostly on the basis of ionization.

Under precisely defined conditions, the energy transfer of nuclear radiation to an irradiated substance can be described by the number of ion pairs formed in a particular volume or mass [weight] unit. In this case, the ion dose will grow, the higher the degree of ionization of the corresponding body happens to be.

Concerning the effect of this kind of nuclear radiation dose on the human organism, the magnitude of the energy given off to the irradiated tissue, the specific ionization, and the time distribution of the radiation effect are decisive among other things. Because the various types of nuclear radiation also cause differing physical and biological effects even when the number of ion pairs formed in a certain volume or mass unit is the same, we can say that a definition of an ion dose, that would be equally valid for all types of nuclear radiation, is basically impossible.

This is why the following applies:

The concept of the ion dose--hereafter briefly called nuclear radiation dose or radiation dose--will be used below only for gamma radiation and x-ray radiation (strictly speaking here again only in an energy range of several keV to a maximum 3 MeV).[2] It is characterized by the number of ion pairs in a certain volume or mass unit.

If one labels the number of gamma quantums with an average energy $\bar{E}_\gamma$/MeV which, per second, enter or leave a surface area of 1 cm^2 standing perpendicularly to the direction of propagation of radiation, using the term N_γ/quantums sec^{-1} cm^{-2}, then, under these conditions, the definition of gamma radiation intensity comes out as follows:

$$I_\gamma = \bar{E}_\gamma \cdot N_\gamma \quad \mathrm{MeV\,s^{-1}\,cm^{-2}} \qquad (5.1)$$

The ionization energy ΔE_I, given off per centimeter of distance due to the reciprocal effect of gamma radiation with the atoms of the irradiated substance, can in this context generally be numerically expressed as follows for the volume unit:

$$\Delta E_I = I_{\gamma_1} - I_{\gamma_2}$$

But this does not as yet tell us anything about the number of ion pairs equivalent to this ionization energy ΔE_I [illegible in photostat]. Instead, this also gives us a second restriction for the term ion dose.

The energy amount to be expended for the formation of an ion pair is specific for each substance; this is why the concept of ion dose can be reproduced only on the condition that one relates it to one and the same substance.

Air was assumed to be this substance and the unit of ion dose is defined as follows:

1 roentgen (R) is the unit of ion dose of gamma or Roentgen radiation which in the mass of 1 kg of air directly or indirectly generates ion pairs with a total charge of $2.58 \cdot 10^{-4}$ Coulomb; this corresponds to $2.083 \cdot 10^{9}$ ion pairs cm^{-3} in air at 0° C and 760 mm Hg:

$$1 \text{ Roentgen} = 2.58 \cdot 10^{-4} \text{ Coulomb kilogram}^{-1}$$

$$1 \text{ R} = (1r) = 2.58 \cdot 10^{-4} \text{ C kg}^{-1}$$

The symbol for the ion dose in military terminology is D. (But it has been proposed to use the symbol Δ for the ion dose and to use D only for the energy dose.)[3]

To give the reader a certain idea of the definition given above, we present some numerical values below; 1 Roentgen of gamma radiation produces the following:

In Air: $2.08 \cdot 10^{9}$ ion pairs cm^{-3}
$1.6 \cdot 10^{12}$ ion pairs g^{-1}

In body tissue: $1.6 \cdot 10^{12}$ ion pairs cm^{-3}
$1.6 \cdot 10^{12}$ ion pairs g^{-1}

Energy absorption at an ion dose of 1 R is approximately as follows:

84 erg g^{-1} in air,
94 erg g^{-1} in body tissue,
150 erg g^{-1} in bone tissue.

An average of 32.5 eV will be needed to form an ion pair in air.

The fact that the unit of ion dose is related to air can be explained in the light of the following:

First of all, the degree of ionization of the air is measured most easily; besides, the energy absorbed by 1 cm^3 of live tissue and the energy absorbed by 1 cm^3 air are proportional to each other at the same ion dose over a broad range of gamma radiation.

This is why it is simplest for radiation measurements under field conditions to conclude from the particular gamma radiation ion dose directly as to the anticipated biological damage.

5.1.1.2. Energy Dose

The energy dose is generally described by the magnitude of energy which any nuclear radiation gives off to a unit of mass [weight] of any substance. The unit of energy dose is the rad (radiation absorbed dose).

1 Rad (rd) is the unit of energy dose of nuclear radiation which directly or indirectly provides the energy 10^{-2} Joule for the mass of 1 kg of an irradiated substance.

$$1 \text{ Rad} = 10^{-2} \text{ Joule Kilograms}^{-1} = 10^{2} \text{ Erg Grams}^{-1}$$
$$1 \text{ Rad} = 1 \text{ rd} = 10^{-2} \text{ J kg}^{-1} = 10^{2} \text{ erg g}^{-1}$$

The peculiarity of the rad as a unit of measurement thus consists in the fact that, in contrast to the unit called Roentgen, it applies to all types of nuclear radiation and to any substance because it is not the number of ions formed which is decisive here but rather the magnitude of energy absorbed. This undoubtedly is an advantage from certain angles. For dose investigations under field conditions one must however keep in mind that a direct measurement of the energy dose is presently impossible; instead, it can in practice be determined only via the ion dose.

The connection between the Roentgen and Rad units turns out to be very simple for gamma radiation.

It follows from the definition of the unit of measure called Roentgen that 1 R corresponds to an energy absorption of 84 erg/g of air, 94 erg/g of body tissue, or 150 erg/g of bone tissue. Because 1 Rad corresponds to an energy absorption of 100 erg/g--regardless of the type of substance irradiated--we must equate 1 R to 0.84 Rad for air, 0.94 Rad for body tissue, and 1.5 Rad for bone tissue.

It was pointed out earlier that the various types of nuclear radiation cause differing biological effects even if the energy dose or the ion dose is the same. The cause of this resides among other things in the specific ionization of the individual types of nuclear radiation. For example, the local ion concentration due to the effect of the neutron flow is considerably higher than in the case of gamma radiation under identical conditions.

In this connection one speaks of the relative biological effectiveness and expresses it, for the various types of nuclear radiation, by means of the RBW factors or, recently, also by means of quality factors (QF).

The biological effectiveness of nuclear radiation is expressed by means of the biological Roentgen equivalent (roentgen-equivalent-man) with the unit called rem.

1 rem is that energy dose absorbed by the tissues which causes the same biological effect as 1 Roentgen [x-ray] or gamma radiation.

In general, the following applies:

$$\frac{\text{Dose}}{\text{rem}} = \frac{\text{Dose}}{\text{Rad}} \cdot \text{QF}$$

Table 5.1 presents some figures for guidance on the quality factors involved in various types of nuclear radiation.

Table 5.1. Quality Factors (QF) to Determine Dose Equivalents according to Formula 5.2[4]

X-ray and gamma radiation, electron and beta radiation with E_{max} greater than 30 keV	1.0
Slow neutrons	5
Fast neutrons and protons	10
Alpha radiation	10
Heavy recoil nuclei	20

The values given here however practically apply only to long-term radiation. For rough approximation calculations on the effect of the neutron component of instantaneous nuclear radiation, we can set the value of QF equal to 1 to 2 (?). But the literature on the subject presently still contains highly contradictory data on this score.

The unit of measure called rem will hereafter be used only to describe the magnitude of the neutron radiation dose.[5]

5.1.2. The Gamma Component of Instantaneous Nuclear Radiation

After a nuclear weapon detonation one can generally distinguish three sources of the gamma component in instantaneous nuclear radiation:

The fission products,

The reaction of the neutrons with the nitrogen in the air,

The chain reaction.

But only the two first-named sources provide a decisive contribution to the total dose of gamma radiation during the defined action time of instantaneous nuclear radiation.

Fission products as gamma radiation source are found in the fireball or in the detonation cloud and rise with them. The composition of the fission product mixture and thus also its properties to a certain extent depend on the nuclear charge used and on the energy of the neutrons triggering fission.

The initial radioactivity of fission products per kiloton of detonation energy is on the order of magnitude of 10^{11} Curie.

In general one can say that, as a result of direct nuclear fission, a mixture of approximately 60 radio nuclides made up of 35 chemical elements is formed and their mass numbers are in the range of A = 70 to A = 160.

Most of these radionuclides and their decay products emit high-energy gamma radiation.

One may assume that, within a period of up to 10 sec after a nuclear weapon detonation, an average of 3-4 quantums will be emitted per nucleus split. The energy of the very short-lived nuclides, which is of interest here, will fluctuate within a very broad range and changes very much with the time that has elapsed since the detonation.

In rough investigations it is however permissible to figure on an average quantum energy of 2 MeV of gamma radiation from fission products during the time interval of instantaneous nuclear radiation.

The free neutrons developing after a nuclear weapon detonation among other things react with the atomic nuclei of the nitrogen in the air. Here we get a neutron capture reaction $^{14}N9n, \gamma)^{15}N$ as a result of which highly intensive gamma radiation is emitted.

The action duration of this gamma radiation depends on the action time of the prompt neutrons (see Section 5.1.3) and accordingly amounts to only fractions of seconds. The average energy of the quantums of this capture gamma radiation is on the order of 4-6 MeV.

The chain reaction as another prompt gamma radiation source therefore only has very little significance because these gamma quantums are emitted at a moment at which the nuclear weapon has not yet decayed [broken apart] and this of course means that the casing provides a very strong weakening effect.

After a nuclear weapon detonation, the dose rate decreases very rapidly in terms of time. After just a few seconds, it amounts to only fractions of the initial dose rate.

This is due not only to the short action time of gamma captured radiation but particularly to the rapid decay of the short-lived fission products and the fact rise of the detonation cloud in which the mass of the radionuclides is located. Accordingly, the increase in the summary gamma radiation dose of instantaneous nuclear radiation is also greatest at the start of the radiation time.

This situation is illustrated in Figure 5.1.

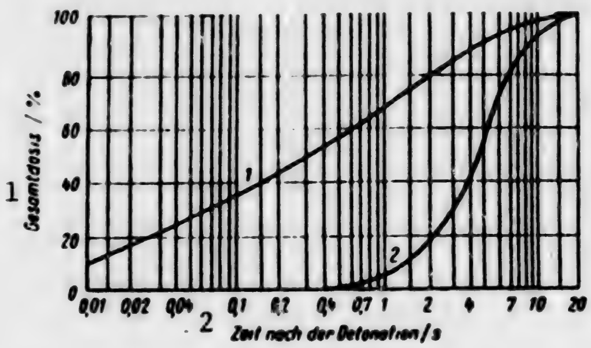


Figure 5.1. Increase in summary dose from gamma radiation for various detonation intensities. Key: 1--Total dose, %; 2--Time after detonation, sec. Curve 1 applies when q = 20 kt and when we have a distance of 900 m from the detonation point; curve 2 applies with q = 50 Mt and we have a distance of 2,300 m.

In case of multi-phase nuclear weapons, the character of the gamma component of instantaneous nuclear radiation, like that of instantaneous nuclear radiation as a whole, will depend heavily on the construction.

In case of three-phase nuclear weapons (casing consisting of U-238), the instantaneous nuclear radiation qualitatively corresponds to that of nuclear fission weapons. But the energy of the emitted neutrons is partly considerably greater. The fission products here again form the main source of gamma radiation.

In two-phase nuclear weapons on the other hand the fission products recede greatly as a gamma radiation source (when we work with a nuclear fission fuse) or they are entirely absent (nuclear synthesis weapon).

The gamma radiation appearing after these detonations therefore comes mostly or completely from the nitrogen neutron capture reactions.

5.1.3. Neutron Component of Instantaneous Nuclear Radiation

The description of the neutron component of instantaneous nuclear radiation is considerably more complicated than that of gamma radiation because the design and construction conditions and the course of energy release in the particular nuclear weapon have an extraordinarily severe effect. This is why it is possible at this point only to explain some generally valid problems in an elementary fashion.

In contrast to gamma radiation, neutron radiation appears only in the volume of instantaneous nuclear radiation as annihilation factor.

Here it is basically possible to distinguish three sources of neutron radiation:

The chain reaction,

Various types of nuclear synthesis reactions,

Fission products.

The free neutrons (fission neutrons), which develop during the process of the chain reaction following the use of nuclear fission weapons are called prompt neutrons because they are emitted during a time interval of less than 10^{-6} sec.

This prompt neutron accounts for more than 99 percent of all neutrons emitted from nuclear fission weapons.

On the average we can assume that, when we use U-235 as the nuclear charge, 1.5 neutron and, in the case of Pu-239, 2 neutrons per fission act will not be participating in the continuing chain reaction. Most of these prompt neutrons, with an energy of $\bar{E}_n$ = 1 MeV, are severely attenuated (moderated) by the nuclear weapon's casing so that, by the time the casing has evaporated, its maximum energy on the average will no longer exceed 5 keV. This means that the range of these moderated neutrons will be only relatively short and, in the area around the detonation center, there will be a highly-concentrated neutron cloud with a radius of several hundred meters.

The smaller part of the prompt neutrons penetrates the neutron cloud and, because of its energy, which is 0.4-0.6 MeV, spreads over relatively long distances.

In the case of multi-phase nuclear weapons, and of course also, in nuclear synthesis weapons, we must consider a series of thermonuclear reactions as neutron sources.

The resultant free neutrons are distinguished by particularly high energies. The number of neutrons, emitted in this fashion per kiloton of detonation energy, as well as their energy spectrum, will vary very much as a function of the particular weapon type. Here we are likewise dealing with prompt neutrons.

The fundamental synthesis reactions are explained for two-phase nuclear weapons with lithium-deuteride charge in Section 1.4.2.2. More detailed investigations show that the probability for the course of the reactions:

$$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{4}_{2}He + ^{3}_{1}H + 4.8\ MeV \quad (a)$$

and

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6\ MeV \quad (c)$$

here is 100 times greater than for the other reactions.

Out of the total reaction energy accounted for in reaction (c), the released neutron alone carries about 14 MeV.

These neutrons enter into a reciprocal relationship with the nuclei of the nonfissioned part of the nuclear charge as well as various other substances in the nuclear weapon and lead to nuclear reactions of type (n, 2n). Processes of inelastic scatter are very probable furthermore in conjunction with nuclei of various heavy elements. In this way we get neutrons with an energy of about 4 MeV.

The neutron spectrum appearing after the detonation of three-phased uranium-casing nuclear weapons is described by Lavrenchik (Figure 5.2).[6]

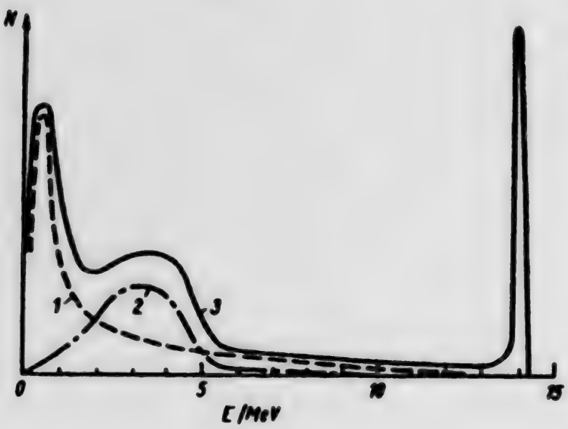


Figure 5.2. Hypothetical neutron spectrum in the case of three-phase nuclear weapons (fission--synthesis--fission).

Accordingly, the hypothetical neutron spectrum, developing on the basis of the processes of nuclear fission--nuclear synthesis--nuclear fission consists of three fundamental components:

Fission neutrons with a relatively tight distribution maximum around 0.7 MeV (Curve 1);

Neutrons which are produced as a result of the inelastic scatter of the superfast nuclear synthesis neutrons, with a broad distribution maximum at 4 MeV (Curve 2);

Neutrons which rise immediately as a result of the nuclear synthesis reactions with a sharp peak distribution maximum at 14 MeV (Curve 3).

In this description, no further consideration was given to the moderation of the neutrons by the material of the nuclear weapon. This is why one must assume that the energy distribution of the neutrons will heavily shift into the left part of the spectrum, considering the numerous braking effects which appear.

Summarizing this problem complex we can thus establish that the real relationship between the three fundamental neutron components can develop in a highly variable fashion as a function of the share of the three phases of energy release out of the total energy and the balance developing between fission and synthesis as well as the construction of the nuclear weapon.

Along with the prompt neutrons in the chain reaction, nuclear fission also results in delayed neutrons which are caused by the decay of a series of fission products. Although, gauging by the total number, they account for less than 1 percent, they nevertheless are extraordinarily important, as we will describe later on.

According to Gurevich and Miekhin,[7] one can approximately describe the neutron spectrum emitted by fission products as follows:

$$N(E) \approx \sinh \sqrt{2E \cdot e^{-E}} \qquad (5.3)$$

whereby E is the energy of the neutrons.

Here, the distribution N of the neutrons begins at about 0.02 MeV and extends all the way to 15 MeV.

These delayed neutrons take effect up to several seconds after the detonation. The fragments resulting from nuclear fission partly reveal a considerable neutron surplus. It might be recalled that the ratio between the number of neutrons and the number of protons is roughtly 1.6 for neutrons of heavy elements at the end of the periodic system, whereas it is 1.3 for the nuclei of stable elements on the order of magnitude of nuclear fragments (fission products).

Concerning its energy, the neutron spectrum of a nuclear weapon detonation is usually subdivided into three groups:

Fast neutrons ($E > 1$ MeV);

Medium-fast or intermediate neutrons ($100 \text{ e V} \leqq E \leqq 1$ MeV);

Slow neutrons ($E < 100$ eV).

This subdivision makes it considerably easier to describe the reciprocal action processes of the neutrons.

In conclusion we must stress that the term "neutron flux" is in current usage in two ways. First of all, it is generally used for an overall description of the neutrons released after nuclear weapon detonations; besides, as a parameter, it describes the number of neutrons which, throughout the entire action time of instantaneous nuclear reaction, will act upon a surface area of 1 cm^2 located perpendicularly with respect to the direction of propagation.

Review Questions

5.1. Why do we distinguish between instantaneous and residual nuclear radiation in nuclear weapon detonations?

5.2. Explain the essential content of the terms "ion dose" and "energy dose."

5.3. How must the dose unit called "Roentgen" be interpreted in military terminology?

5.4. Explain the most important sources of gamma and neutron components in instantaneous nuclear radiation. What is the basic influence of the type of energy release from the particular nuclear weapon in this context?

5.5. Why is an exact evaluation of the neutron doses and neutron spectrums, appearing at the various ranges from the detonation center, extraordinarily complicated?

5.2. Propagation of Instantaneous Nuclear Radiation

The total dose of instantaneous nuclear radiation at the particular distances from the detonation center is always made up of the partial doses of gamma radiation and neutron radiation.

In general, the following applies

$$D_{ges} = D_\gamma + D_n \qquad (5.4)$$

[ges--total]

Gamma radiation and neutron radiation spread in the atmosphere according to differing laws and are therefore subjected to specific reciprocal processes.

This is why it is necessary separately to investigate the propagation of both components of instantaneous nuclear radiation.

Because of manifold influencing magnitudes, which take effect here, we can however below describe only a few basic laws. It might be noted in passing that an exact calculation of the effective doses of instantaneous nuclear radiation is connected with some difficulties. The computation foundations given therefore are only guidance values.

5.2.1. Basic Laws of Gamma Radiation Propagation

The gamma radiation dose D_γ--which appears at a certain place during the action time of instantaneous nuclear radiation--is generally a function of the detonation intensity and the distance from the detonation center.

As in the case of light radiation, there are two processes which have an effect on the propagation of gamma radiation:

First of all, the magnitude of the dose D_γ changes inversely proportionally to the square of the distance from the detonation center;

Second, reciprocal processes of the gamma quantums with the atoms in the air are superposed, during this decline, in the form of absorption and scatter.

The scope of these reciprocal effects of gamma radiation with the air in particular depends on the air density. In addition to the detonation altitude it is therefore also the blast wave's propagation mechanism which plays an essential role in the computation of the gamma radiation doses appearing at the individual distances.

The situation can be described as follows in a simplified form. The summary gamma radiation dose at any desired distance from the detonation center (ground

zero) is practically always made up of the doses of gamma radiation of the fission products ($D_{\gamma_{Sp}}$) [Sp--fission] and the gamma radiation of the neutron nitrogen capture reactions (D_{γ_n}).

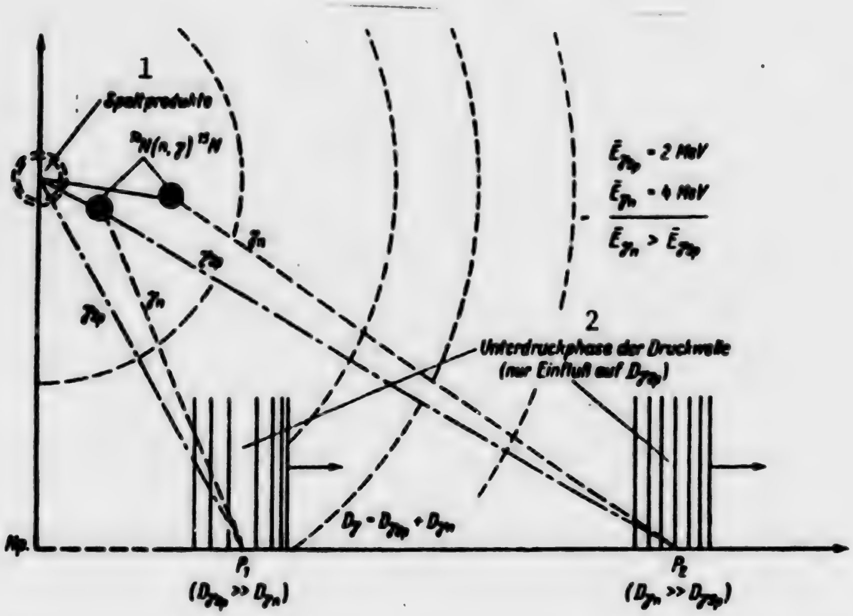


Figure 5.3. Diagram illustrating the propagation of the gamma component of instantaneous nuclear radiation. Key: 1--Fission products; 2--Blast wave's underpressure phase (influencing only $D_{\gamma_{Sp}}$).

Both shares of the total dose however are not constant but rather change with the detonation intensity and the distance.

As we explained in Section 5.1.2, the gamma radiation of the neutron capture takes effect only in fractions of seconds. During that time, the blast wave is still rather undeveloped, that is to say, the underpressure phase is short and therefore only slightly influences the propagation of this gamma radiation. Conditions are different regarding the gamma radiation of the fission products. Their action time even in case of smaller detonation intensities comes to several seconds so that the effect of the blast wave's underpressure phase, which diminishes the attenuation, can become fully effective.

Because the blast wave's action time generally and thus also the underpressure phase depend on the detonation intensity, it follows that the share of the gamma radiation of the fission products out of the summary gamma radiation dose will grow constantly as the detonation intensity goes up.

The change in the shares with the distance (when q = constant) can be explained in the light of the differing energy of both radiation components. Due to the scatter and absorption, the gamma radiation dose decreases constantly, whereby the gamma quantums coming from the neutron capture reactions ($\bar{E}_\gamma \approx 4$ MeV)

however have a considerably greater range compared to those of the fission products ($\bar{E}_\gamma \approx 2$ MeV). This is why one may assume for distances of r > 2,000 m that D_γ will here be practically equal to D_{γ_n}.

By way of approximation one can describe the change in the gamma radiation doses with the distance from the detonation center with the help of the following expression:

$$D_\gamma = \frac{k}{r^2} \cdot e^{-\frac{r}{250}} \qquad (5.5)$$

k—a coefficient which depends on the detonation intensity and which takes into account the proportional quantity of fission products and the action time of the underpressure phase via several intermediate magnitudes;

r—distance from detonation center, m;

r/250—exponent considering the weakening of gamma radiation of the given energy by the air.

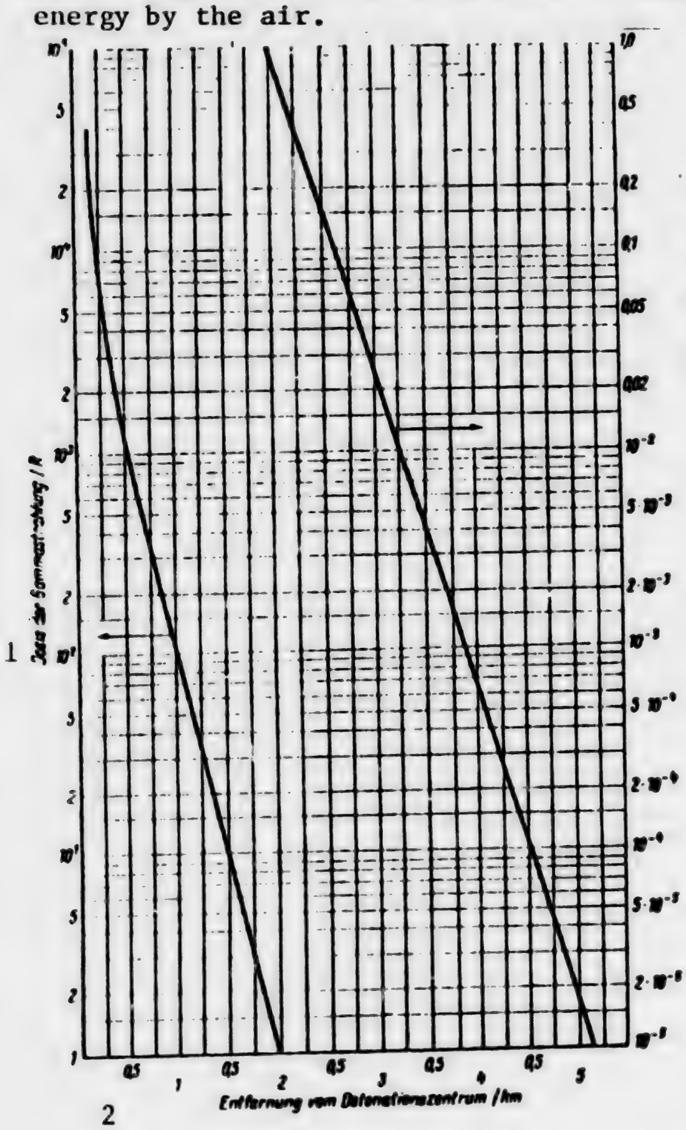


Figure 5.4. Gamma radiation doses as function of the distance for a 1-kt air burst.[8]
Key: 1—Gamma radiation dose, R; 2—Distance from detonation center, km.

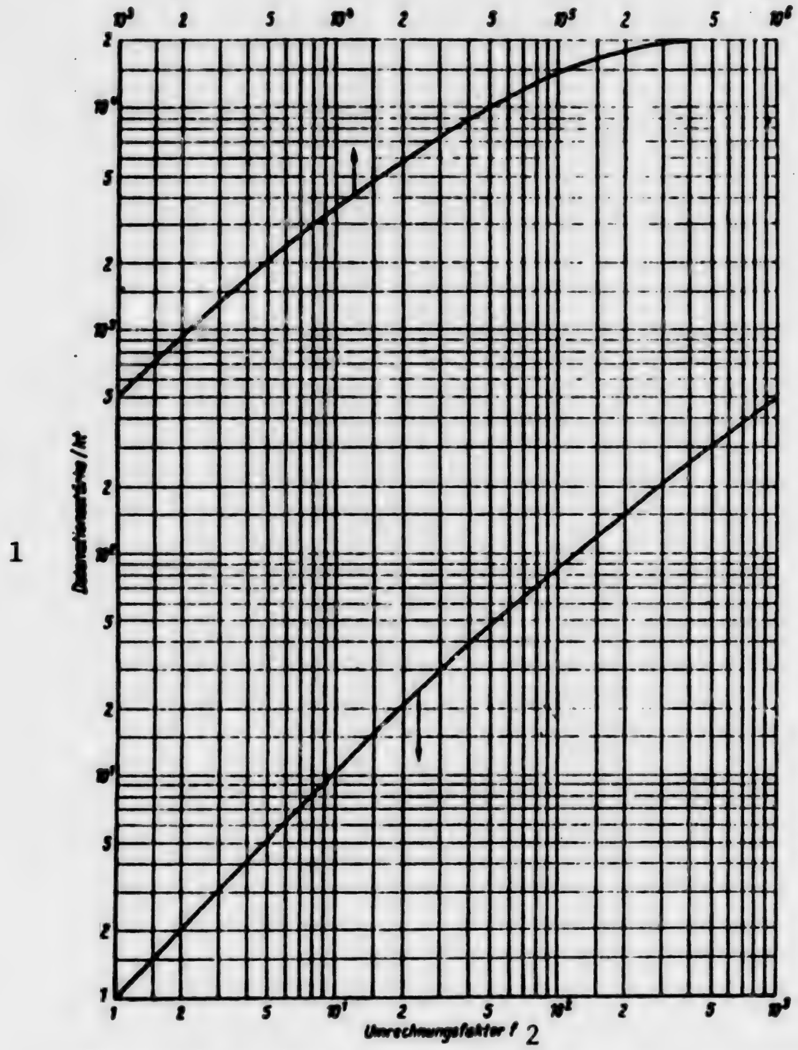


Figure 5.5. Conversion factors for gamma radiation doses when q > 1 kt.[8]
Key: 1--Detonation intensity, kt; 2--Conversion factor f.

As we said earlier, the coefficient k itself again is a magnitude that depends on several factors and whose clear determination is rather complicated.

This is why the nomograms in figures 5.4 and 5.5 should be used for practical calculations.

In the nomogram in Figure 5.4, the gamma radiation doses are illustrated as a function of the distance from the detonation center for an air burst with a detonation intensity of q = 1 kt. For the same distances, we can estimate the effective gamma radiation doses for every other intensity in that one multiplies the dose value read off for 1 kt by the corresponding conversion factor of the nomogram in Figure 5.5.

Problem: estimate the gamma radiation dose appearing after an air burst of q = 200 kt at a distance of 2 km from the detonation center.

Solution:

From the nomogram in Figure 5.4, we read off the value $D_\gamma = 1$ R for $q = 1$ kt and $r = 2$ km.

The conversion factor of $q = 200$ kt turns out to be $f = 300$ from the nomogram in Figure 5.5.

The nomograms (figures 5.4 and 5.5) are based on test detonations which were generalized accordingly.

If similar rough calculations are to be made for ground bursts, then the values, determined for an air burst of equivalent intensity, must be multiplied by the factor 0.7. This procedure, to be sure, is not too accurate but does satisfactorily give us the orders of magnitude.

5.2.2. Basic Laws of Neutron Radiation Propagation

As we saw already from the general description of the neutron component in Section 5.1.3, the description of neutron radiation propagation is rather complicated. A generalization is possible only on the assumption of a series of simplifications.

In nuclear fission or nuclear synthesis reactions we get approximately one free neutron for every 120 MeV of released total energy. This is why one may assume that we get about $2.25 \cdot 10^{23}$ neutrons for a detonation intensity of 1 kt.

These neutrons, which already have differing energies, are propagated to all sides, just like the gamma quantums, and enter into a reciprocal relationship with the atomic nuclei of the material of the nuclear weapon and of the air or the surrounding medium.

The quantity and quality of these reciprocal processes leading to an attenuation of neutron radiation depend on the energy of the neutrons itself and on the specific effect cross-sections of the individual nucleus types.

In contrast to gamma radiation, the change in the neutron dose as a function of the distance from the detonation center cannot be described by means of a simple mathematical relation for the total range.

Yampolskiy,[9] for example, proved that one can reproduce the neutron doses in the air at distances $r < 500$ m from the detonation center by means of a Gaussian curve and, at greater distances, by means of an exponential function.

Due to the differing energy and thus also the range of the neutrons and the effect of the material in the nuclear weapon as well as the variable air density during the passage of the blast wave, one must continue separately to compute the magnitudes of the neutron flux or the neutron doses for the prompt and the delayed neutrons.

The mathematical expressions suitable for this have the following form:

$$D_n = \frac{a \cdot q}{r^2} \cdot e^{-\frac{r}{x}} \qquad (5.6)$$

whereby values for a and x depend on the distance and furthermore differ for the prompt and delayed neutrons.

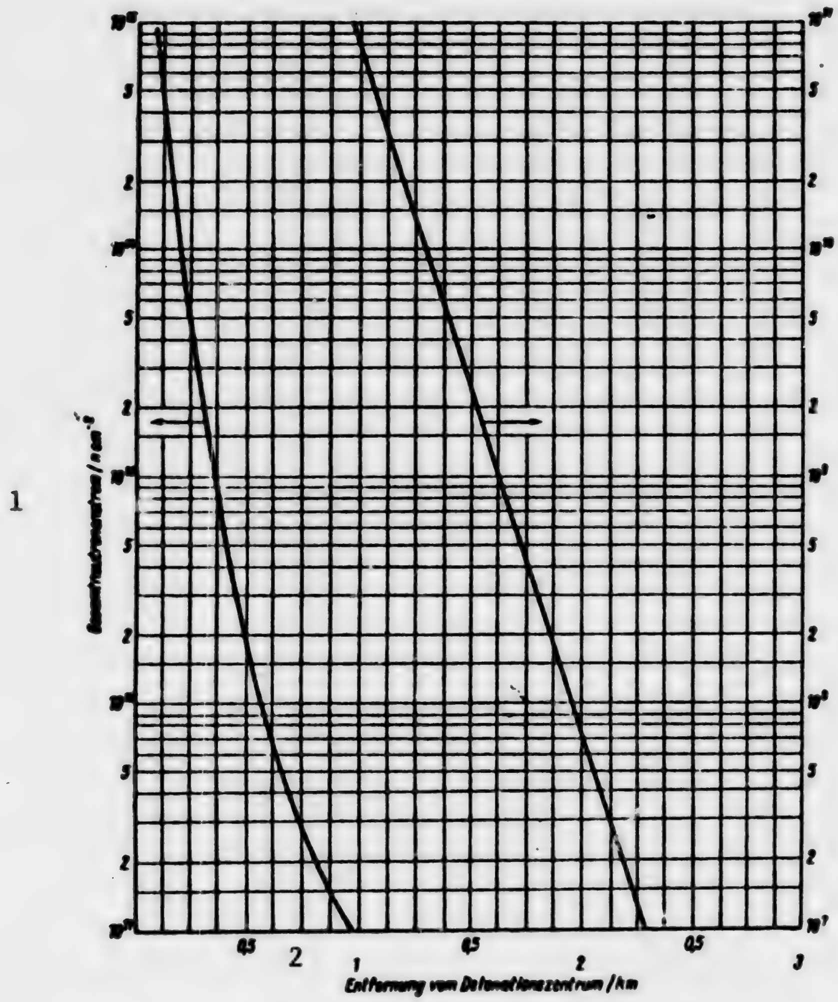


Figure 5.6. Total neutron flux as function of distance for 1-kt air burst.[10]
Key: 1--Total neutron flux, n/cm^{-2}; 2--Distance from detonation center, km.

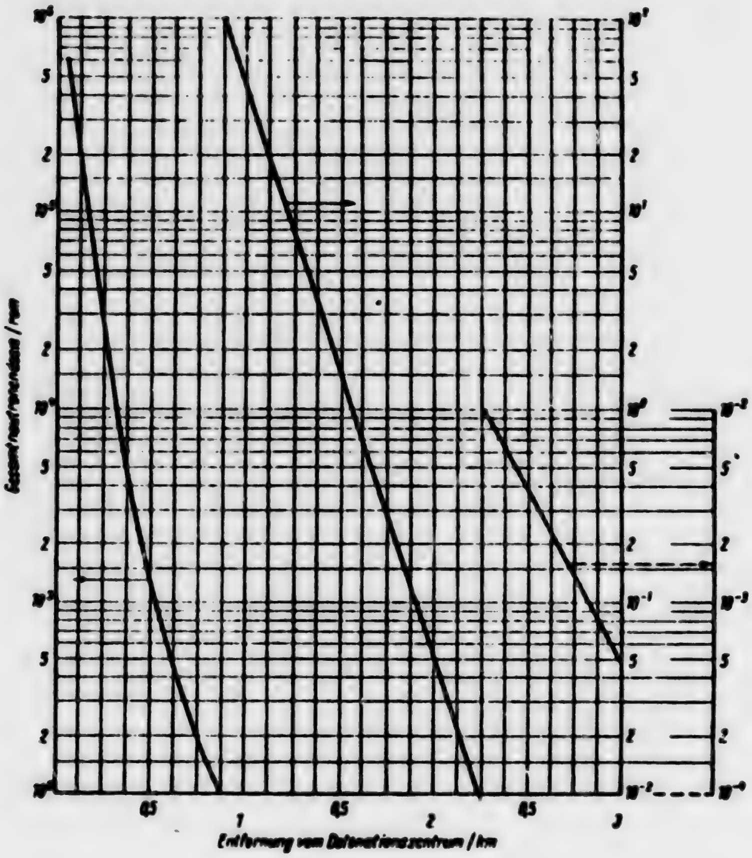


Figure 5.7. Total neutron dose as function of distance from 1-kt air burst. Key: 1--Total neutron dose, rem; 2--Distance from detonation center, km.

Experimental data show that neutrons of differing energy appear at the very distances from the detonation center. This is obviously due to the fact that, on the one hand, slow neutrons are captured, while, on the other hand, fast or medium-fast neutrons gradually lose energy due to scatter processes so that we get a certain spectral balance.

The nomogram in Figure 5.6 contains guidance values for the total neutron flux as a function of the distance for a detonation intensity of q = 1 kt.

The nomogram in Figure 5.7 contains similar values for the total neutron dose.

This last nomogram was based on the assumptions that, for neutrons with energy $E_n > 0.1$ MeV, the biological effectiveness can roughly be considered as being independent of the energy and that, for a total neutron flux from a nuclear weapon detonation of 1 rem about $1.5 \cdot 10^9$ neutrons per square centimeter would be equivalent.

In estimating the numerical values given, one must keep in mind by way of restriction that, depending upon the specific design principle and the type of energy release, deviations up to a maximum of 500 percent are possible. This also explains the numerical data which differ greatly from each other in various publications.

The nomograms given here can be used for rough computations in the case of air bursts and ground bursts. For detonation intensities of $q \neq 1$ kt, we can determine the corresponding neutron doses or values of the neutron flux through multiplication with the detonation intensity q in a simple and adequately accurate manner.

Figure 5.8 shows the shares of the neutron dose or the gamma radiation dose out of the total dose of instantaneous nuclear radiation as a function of the detonation intensity for various distances.

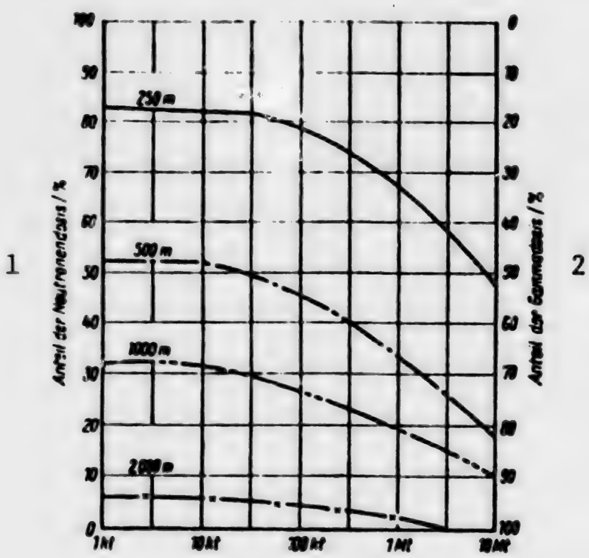


Figure 5.8. Shares of neutron dose and gamma radiation dose out of total dose of instantaneous nuclear radiation as a function of the detonation intensity for various distances from the detonation center. Key: 1--Share of neutron dose, %; 2--Share of gamma dose, %.

We can see that the shares of neutron doses out of the total doses decrease as the detonation intensity increases. In the case of nuclear weapons with detonation intensities in the subcaliber range, the neutron component of instantaneous nuclear radiation is absolutely decisive with relation to the annihilating overall effect; on the other hand, in nuclear weapons with great intensity, gamma radiation assumes more and more significance at the distances that are of interest here especially since the neutron doses at all detonation intensities shrink rapidly as the distance grows.

Although the propagation speed of the neutrons in contrast to gamma radiation is below the speed of light, one may assume that the total neutron doses at the particular distances in practice take effect within a span of 1-2 sec so that protection against this component of instantaneous radiation by taking cover is extremely problematical.

It must furthermore be kept in mind that the share of scatter radiation in the neutron flux is still by far greater than in the case of gamma radiation. It can be as much as 10 percent of the particular directly incident dose.

This fact means that persons in open combat vehicles or in uncovered trenches can also be harmed if they have avoided the direct incidence direction from the detonation center. The processes connected with this were described in greater detail in Section 5.3.

Review Questions

5.6. Which general laws form the basis of the propagation of gamma radiation in the air?

5.7. Why does the air blast wave greatly influence the propagation of gamma radiation?

5.8. How is the total dose of gamma radiation composed at the particular distances from the detonation center?

5.9. What general laws constitute the foundation of the propagation of neutron radiation in the air?

5.10. Why do we get neutrons of differing energy at the same distances from the detonation center?

5.11. In connection with the spread of instantaneous nuclear radiation, interpret the term "scatter radiation."

5.3. Annihilating Effects of Instantaneous Nuclear Radiation and Protection against Them.

The annihilating effects of instantaneous nuclear radiation are based directly or indirectly on the radiation damage caused by ionization in living or inanimate substances.

Here, we get some analogies between instantaneous nuclear radiation and residual nuclear radiation. It is therefore possible to investigate and explain certain physical and radiation-biology problems which are common for both annihilation factors.

The arrangement selected here primarily takes into account methodological aspects.

5.3.1. Effect of Instantaneous Nuclear Radiation on an Object

Both components of instantaneous nuclear radiation (gamma radiation and neutron radiation) have certain effects on an object in common whereas they differ in other respects.

From the viewpoint of the overall effect of a nuclear weapon detonation we are particularly interested here in three groups of problems:

The radiation damage anticipated in human individuals as a function of the effective total dose of instantaneous nuclear radiation;

The radioactivity induced as a result of neutron capture;

Radiation damage in inanimate substances, such as changes in the properties of the electronic structural elements, resistance changes in metals,

discoloration or clouding of glasses, destruction of certain plastics which however normally would appear only at very high radiation doses and therefore in the case of ground and air bursts in most cases would be blanked out by the annihilating effects of the blast wave and light radiation. This problem complex will be covered in greater detail in Section 5.3.4.

For a better understanding of these questions however it seems necessary to present some elementary statements on the reciprocal processes between radiation and substance as we begin our considerations here.

5.3.1.1. Reciprocal Effect Processes between Gamma Radiation and Substance

The reciprocal effect between gamma radiation and the irradiated substance encompasses three processes:

The photo effect (photoelectric absorption);

The Compton effect (inelastic collision with electrons);

The pair formation effect.

Each of these reciprocal action processes appears on a priority basis in a certain energy range and with certain substances.

The essence of the photo effect consists in the fact that a gamma quantum with its energy $E_\gamma = h \cdot \nu$ is absorbed by a casing electron and that, as a result of this reciprocal process, its energy is completely consumed. A part of the energy of the gamma quantum is used for the separation work W of the electron, while the other part is given to the electron as motion energy. The free electron causes a secondary ionization on its way.

Each absorbed gamma quantum $E(h \cdot \nu)$ thus in the photo effect primarily relieves [replaces] an electron and imparts to it a velocity which is determined by the following equation:

$$\frac{m}{2} \cdot v^2 = h \cdot \nu - W \qquad (5.7)$$

The separation [replacement] work W for an electron is on the order of magnitude of 30-50 eV.

In the case of the Compton effect, there is a reciprocal relationship between a gamma quantum and an only relatively loosely bound casing electron.

The pushing quantum transits only a part of its energy (separation work and kinetic energy of electron) and is itself diverted from its original propagation direction. We thus get scatter radiation as a result of the Compton effect. It does not reveal any pronounced propagation tendency. In this way, gamma quantums can be scattered several times and this process as a rule is closed out by a photo effect. The recoil electron here again leads to secondary ionizations.

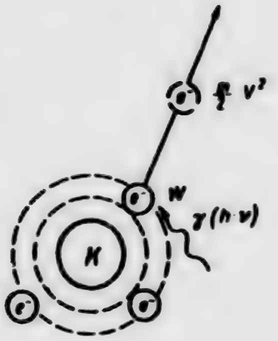


Figure 5.9. Diagram illustrating photo effect.

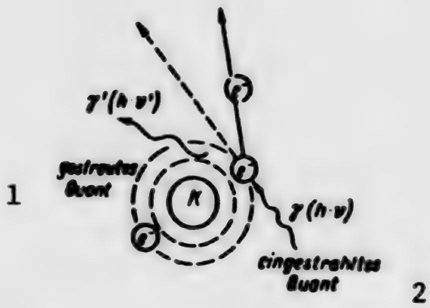


Figure 5.10. Diagram illustrating the Compton effect. Key: 1--Scattered quantum; 2--Quantum radiated in.

In the case of the Compton effect we thus simultaneously get a scattered quantum and a recoil electron. Assuming that the separation work is approximately zero, the energy of the compound electron looks like this:

$$\frac{m}{2} \cdot v^2 = h(\nu - \nu') \qquad (5.8)$$

The pair formation effect is the third and last process in the reciprocal interaction between gamma radiation and the substance.

It consists in the fact that a high energy gamma quantum (E_γ > 1 MeV) in the field of a heavy atomic nucleus can be converted into an electron pair, that is to say, an electron with negative charge (negatron) and an electron with positive charge (positron).

Negatron and positron lead to secondary ionizations.

The original energy of the gamma quantum, after conversion, again appears in the form of the rest mass of the electron pair and its kinetic energy.

It must also be noted that the positron formed here gives its energy off through various shock [collision] processes, that it is united with an electron, and that in this process it annihilates the total mass of both particles (annihilation radiation).

In general, we get two gamma quantums with a summary energy of 1.02 MeV; 0.5 MeV per quantum.

The energy of the electron pair thus is:

$$\frac{m}{2}(v_+^2 + v_-^2) = h \cdot \nu - 2m_0 \cdot c^2 \qquad (5.9)$$

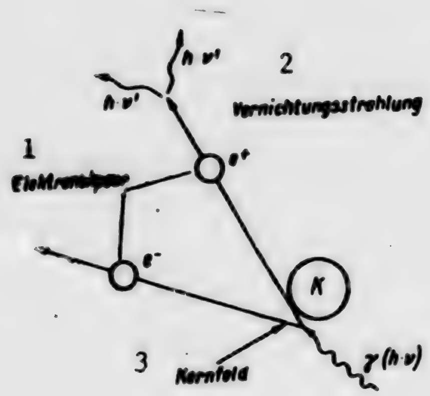


Figure 5.11. Diagram illustrating the pair formation effect.
Key: 1--Electron pair; 2--Annihilation radiation; 3--Nucleus field

5.3.1.2. Reciprocal Action Processes between Neutrons and Substance

In contrast to gamma radiation, neutrons enter into a reciprocal relationship as electrically neutral nuclear particles not with electron envelopes of the atoms but rather with their nuclei. Substances, which they penetrate, there are not directly ionized by them but rather indirectly via recoil nuclei, fission fragments, and secondary radiation from activated nuclides. Neutrons have a great penetration capacity. Free neutrons are unstable and, with a half-life of 12 min, are in each case converted into a proton and an electron.

Various reciprocal action processes are possible as a neutron enters the range of an atomic nucleus. The neutrons are either scattered or they trigger a series of other nuclear reactions.

Specifically, the following processes are basically possible:

Elastic scatter;

Inelastic scatter;

Neutron capture with emission of gamma quantums;

Neutron capture with emission of charged particles;

The splitting of the nucleus (forced fission) along with the action of the neutrons.

A certain effect [action] cross-section can be matched up with each of these processes for a given type of nucleus as a function of the energy of the neutrons. The action cross-sections however change greatly at identical neutron energy but different substances.

In a simplified fashion we can say quite generally that the action cross-sections for the individual neutron reactions will be all the greater, the slower the speed of the neutrons happens to be because in this case they are near the nucleus for a relatively longer period of time.

As we already briefly explained in Section 5.1.3, we get neutrons of differing energy from a nuclear weapon detonation.

Accordingly, the most varied reciprocal action processes between neutrons and the individual substances should also be expected.

Here however we will only take a somewhat closer look at scatter and capture and the most important processes.

The nucleus conversions caused by the neutrons basically involve the formation of an intermediate nucleus.

$$A + n \rightarrow \text{intermediate nucleus} \rightarrow B + b$$

The half-life $T_{1.2}$ of this intermediate nucleus is about 10^{-15} sec.

The essence of elastic scatter consists in the fact that a particle is absorbed by the atomic nucleus and that another particle, of the same type as this particle, is given off. This process is illustrated in the upper part of Figure 5.12 for elastic neutron scatter.

The colliding neutron is absorbed by the nucleus; an intermediate nucleus is formed and it again decays, emitting a lower-energy neutron. As a result of this process, there is a change in the propagation direction of the neutrons, that is to say, they are scattered.

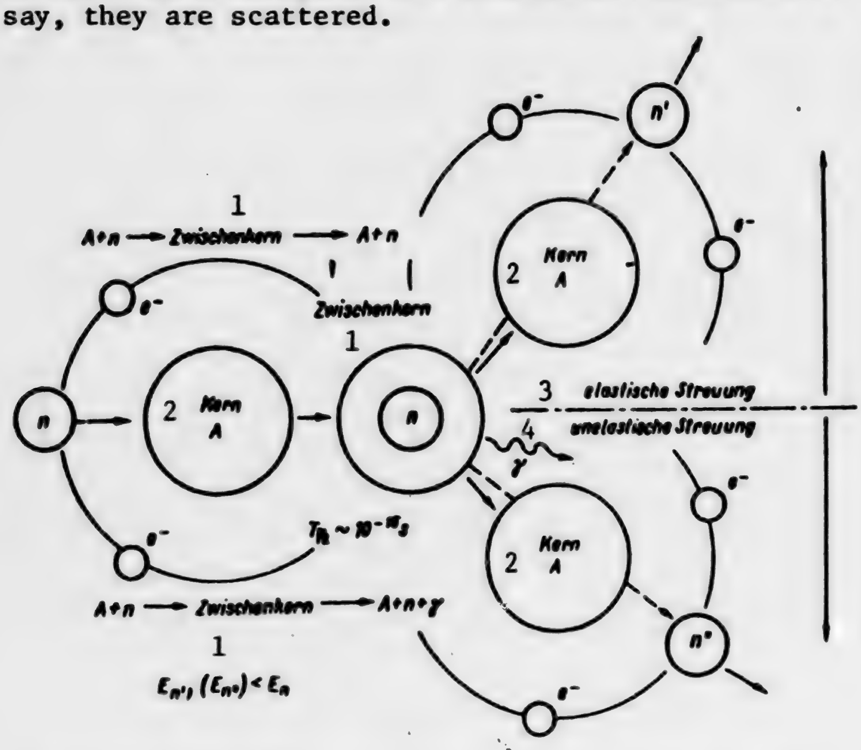


Figure 5.12. Elastic and inelastic scatter of neutrons. Key: 1--Intermediate nucleus; 2--Nucleus; 3--Elastic scatter; 4--Inelastic scatter.

This type of reciprocal effect is characteristic of fast and medium-fast neutrons with any nuclei.

Inelastic scatter is characterized by the fact that, in addition to the emission of an identical particle, that is to say, in our case, a neutron, a part of the kinetic energy of the colliding particle is deflated [radiated away] from the intermediate nucleus in the form of gamma quantums.

This type of interaction is characteristic of fast and medium-fast neutrons with heavy nuclei.

In the case of capture reactions, the colliding particles remain "stuck" in the nucleus. An excited intermediate nucleus is again formed and upon its decay, energy is emitted in the form of gamma radiation, without the basic having to be restored as a result of that. Instead, the excitation energy as a rule is deflected [radiated away] by the following decay of the nucleus thus formed (radioactive capture).

This process is illustrated in the diagram in Figure 5.13.

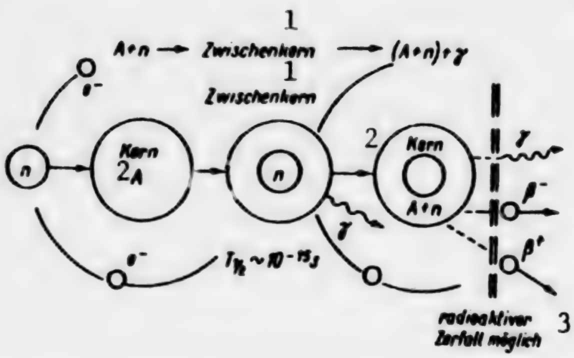


Figure 5.13. Neutron capture.
Key: 1--Intermediate nucleus; 2--Nucleus; 3--Radioactive decay possible.

The most essential process of neutron capture after nuclear weapon detonations thus consists in the fact that, due to the effect of the neutron flux, certain stable nuclides are converted into radioactive nuclides. The activation resulting in this fashion is called neutron-induced activity. Specifically however we will go into this problem complex only in Chapter 7 in our treatment of residual nuclear radiation.

In conclusion it might be observed that neutron capture with subsequent radioactive decay is characteristic of slow and thermal neutrons.

5.3.2. Attenuation of Instantaneous Nuclear Radiation

5.3.2.1. Attenuation of Gamma Radiation

In Section 5.2.1 we already pointed out, in presenting the basic laws of gamma radiation propagation, that the decline in the gamma radiation dose with the square of the distance is superposed by attenuation due to absorption and scatter. After these reciprocal action processes were taken up in detail in

the preceding sections, it is now possible to take a somewhat closer look at the entire process of attenuation.

Basically, one can illustrate the attenuation processes on the basis of the intensity, dose rate, or dose of gamma radiation. Here we will below make reference to the gamma radiation dose.

Gamma radiation has a great penetration capacity. Its intensity and thus the radiation doses approach zero asymptotically as the distance from the detonation center increases.

The degree of attenuation here depends on the energy of gamma radiation and the properties of the medium which is between the radiation source and the reference point considered.

For radiation protection under field conditions the important thing as a rule is to compare a certain defined gamma radiation dose outside a shelter with the dose that takes effect in the shelter.

The attenuation of gamma radiation generally follows an exponential law. For monochromatic radiation, we can formulate the following:

$$D_\gamma = D_{0,\gamma} \cdot e^{-\mu d} \quad R \qquad (5.10)$$

$D_{o,\gamma}$--gamma radiation dose in case of absence of absorbers or at the particular range from detonation center outside shelters

D_γ--gamma radiation dose after penetration of an absorber with the thickness d, cm

μ--linear attenuation coefficient for gamma radiation of given energy, cm^{-1}

d--Thickness of absorber, cm.

Upon passage through a substance, the most important reciprocal action processes of gamma radiation, leading to attenuation, are the photo effect, the Compton effect and the pair formation effect.

This is why the summary linear attenuation coefficient μ consists of the attenuation coefficients of the individual processes. The following applies:

$$\mu(E) = \tau(E) + \sigma(E) + \varkappa(E) \quad cm^{-1} \qquad (5.11)$$

In the energy interval of gamma radiation which is of concern after nuclear weapon detonations it can be assumed that the attenuation of gamma radiation depends primarily on the mass [weight] of the absorber.

In other words, this means that the linear attenuation coefficients of two substances are in the same ratio to each other as their densities.

$$\mu_1 : \mu_2 = \varrho_1 : \varrho_2 \tag{5.12}$$

For practical calculations it is a good idea to introduce the concept of half-life thickness or half-life layer. That is the thickness or layer of an absorber which will weaken the dose of gamma radiation of certain energy by one-half.

The following relationship exists between the half-life layer d and the linear attenuation coefficient μ:

$$d_{1/2} = \frac{0{,}693}{\mu} \text{ cm} \tag{5.13}$$

This can be shown in a simple manner by inserting $d_{1/2}$ into Equation 5.10 ($\ln 2 = 0.693$) [as published].

If one replaces the linear attenuation coefficient μ in Equation 5.10 with the equivalent expression $(0.693:d_{1/2})$, then, after corresponding conversion, we can express the attenuation factor of a given absorber as follows:

$$n = \frac{D_\gamma}{D_{0,\gamma}} = \frac{1}{2^{\frac{d}{d_{1/2}}}} \tag{5.14}$$

If we have several absorber layers of different substances, the resultant attenuation factor turns out to be as follows in a first approximation.

$$n = n_1 \cdot n_2 \ldots n_i \tag{5.15}$$

But now the exponential law of attenuation (5.10) and the derived relations, strictly speaking, are fulfilled for narrow, parallel beams of a monochromatic gamma radiation.

Such radiation conditions however by no means prevail after a nuclear weapon detonation. This is why it is necessary for exact calculations to add some specific statements or to introduce some restrictions with respect to the considerations presented until now.

Gamma radiation of varying energy appears after a nuclear weapon detonation at the various distances from the detonation center. For attentuation calculations one must therefore figure using an average energy value. Regardless of that, this average energy decreases with the distance, whereby the share of scatter radiation keeps growing and accordingly the share of gamma radiation of lower energy out of the effective total dose also grows.

Because we are dealing here with a broad gamma radiation beam, the dose behind an open shelter, due to manifold scatter processes in the absorber material, can be bigger than would be calculated with the simple estimate formulas. But this problem complex will not be covered in greater detail as we go on.

Low-energy gamma radiation is attenuated relatively quickly by an absorber. This is why a strong initial dose decline can take place in the surface layer of a shelter facility if we have a large share of this gamma radiation here.

From these viewpoints, relation 5.14 can be formulated as follows:

$$n = \frac{D_\gamma}{D_{0,\gamma}} = \frac{a}{e^{\mu(eff)\cdot d}} = \frac{a}{2^{\frac{d}{d_{1/2}(eff)}}} \qquad (5.16)$$

a--a factor which allows for the attenuation of the soft gamma radiation in a surface layer x_o; the factor is a function of the distance from the detonation center.

μ_{eff}--effective attenuation coefficient allowing for the energy composition of the gamma radiation dose at the distance considered.

According to Formula 5.13, $d_{1/2(eff)}$ then analogously is the effective half-life layer of the given material for the particular distance.

From the elementary considerations presented here, it follows that the introduction of the correction factor a and the magnitude $\mu_{(eff)}$ or $d_{1/2(eff)}$ cannot indicate any generally valid attenuation factors for an absorber or a shelter facility but rather that the dependence on the distance continues to exist as before.

This is why one can perform rough estimate calculations on the basis of average, maximum, or minimum attentuation coefficients and this is why one will get differing results in this way. This fact must be taken into consideration when comparing numerical data in various literature sources. We will not describe here the change in the linear effective attenuation coefficients as a function of the distance from the detonation center. Instead, this dependence will be illustrated in Figure 5.15 for some materials, using the example of the effective half-life layers which are more important in actual practice.

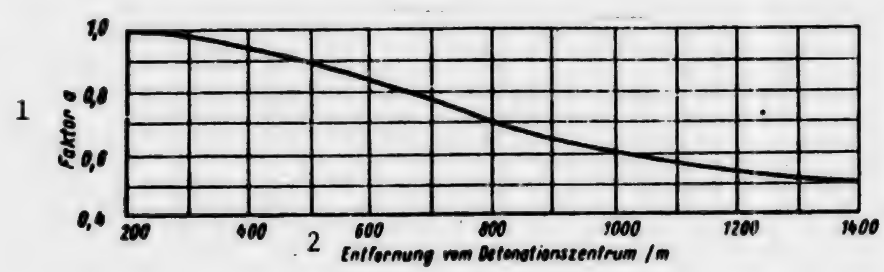


Figure 5.14. Values of the correction factor a as a function of the distance. Key: 1--Factor a; 2--Distance from detonation center, m.

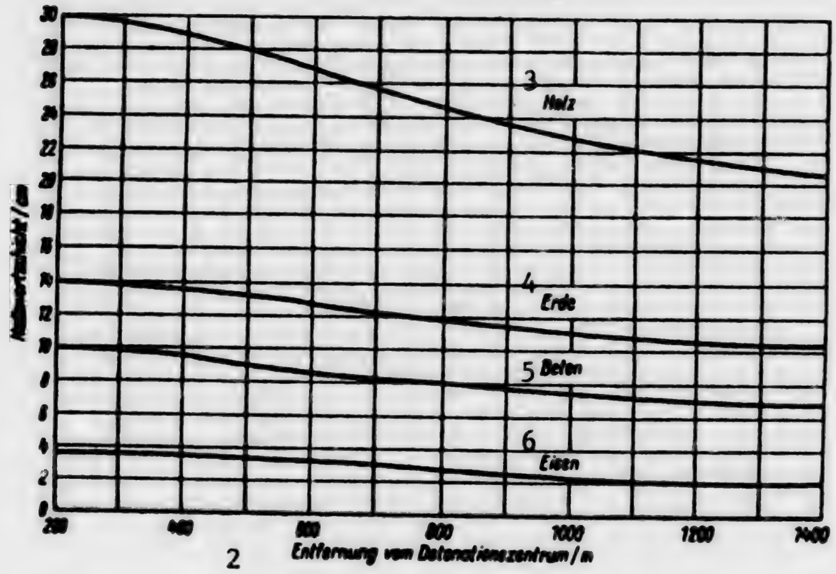


Figure 5.15. Change in effective half-life layers $d_{1/2(eff)}$ for some selected substances as a function of the distance from the detonation center. Key: 1--Half-life layer, cm; 2--Distance from detonation center, m; 3--Wood; 4--Earth; 5--Concrete; 6--Iron.

This illustration clearly shows that the differences arising as a function of the density of the substances are quite considerable. Nevertheless, it is permissable and necessary for rough calculations to work with certain average values.

Table 5.2. Approximation Values for Half-Life Layers $d_{1/2}$ of Various Substances for Gamma Radiation with Average Quantum Energy of 2.5 MeV

Substance	$d_{1/2}$	Substance	$d_{1/2}$
Air	250 m	Earth	14 cm
Snow	50 cm	Concrete	10 cm
Wood	25 cm	Steel	2.8 cm
Water	23 cm	Lead	1.8 cm

To conclude these considerations, we might supply a calculation example.

Problem: at a distance of 1,000 m from the detonation center of a nuclear weapon detonation, we get an outside gamma radiation dose of 100 R. Determine the effective dose behind earth cover with a thickness of 100 cm.

Solution Alternative 1:

According to Formula 5.16, considering the correction factor a, if (Figure 5.14) we insert for 1,000 m a value of a = 0.6 and for $d_{1/2}$ (Figure 5.15) a value of 11 cm, we get the attenuation factor as follows:

$$n = \frac{0{,}6}{2^{\frac{100}{11}}} \approx \frac{0{,}6}{2^9} \approx 0{,}001$$

The effective dose accordingly is:

$$D_\gamma = D_{0,\gamma} \cdot n = 100\,\mathrm{R} \cdot 0{,}001 = 0{,}1\,\mathrm{R}$$

Alternate Solution 2 (Approximation Calculation):

According to Formula 5.14, when $d_{1/2}$ = 14 cm (Table 5.2), we get an attenuation factor of:

$$n = \frac{1}{2^{\frac{100}{14}}} \approx \frac{1}{2^7} \approx 0{,}008$$

The effective dose can be calculated as follows from this:

$$D_\gamma = D_{0,\gamma} \cdot n = 100\,\mathrm{R} \cdot 0{,}008 \approx 0{,}8\,\mathrm{R}$$

This example clearly shows that, depending upon the computation methods elected, there will be considerable differences in the results and that one should therefore avoid any exaggerated accuracy in rough investigations.

5.3.2.2. Attenuation of Neutron Radiation

The attenuation of neutron radiation through an absorber takes place on the basis of the reciprocal action processes of scatter or capture as covered in Section 5.3.1.2.

As in the case of gamma radiation, here again the energy of the neutrons and the density of the substance decisively influence the course of the attenuation processes. In contrast to gamma radiation however there are some special features here.

First of all, it is rather difficult to achieve adequate protection against fast neutrons by means of certain types of cover [shelters]. This can be explained by the fact that, in the case of neutron attenuation, there is no similar proportionality to the density of the absorber material as there is in the case of gamma radiation. Such materials as iron and lead, which have great attenuation coefficients with respect to gamma radiation, proved to be far less effective against the neutron flux. Because many types of nuclei reveal a large capture cross-section only for slow neutrons, the fast neutrons must first be slowed down to medium or low energies by means of manifold scatter processes. Elements with average or small nuclear mass, such as iron, barium, hydrogen, and their compounds are particularly suitable here.

Second, inelastic scatter and neutron capture lead to the development of primary or secondary gamma radiation with partly high quantum energy. This means that a neutron absorber must moreover be so constituted that this gamma radiation cannot come out of the screen. This is why, for example, moist earth

and concrete provide good protection against both components of instantaneous nuclear radiation while in the case of armored vehicles it would in practice be necessary to provide for adequate attenuation of the neutron flux in addition to the armor plating.

Third, one must keep in mind that the processes of scatter lead to a constant change in direction of neutron radiation. It follows from this that even at relatively short distances from the detonation center, neutron radiation will not reveal any clearly pronounced propagation tendency but rather that it will practically act upon an object from all sides. This is why the protective properties of open shelters are only relative, apart from the short action time of neutron radiation.

Fourth, as we already pointed out in Section 5.2.2, a clear determination of the neturon doses, appearing at the particular distances from the detonation center of a nuclear weapon, is rather difficult and can be accomplished in a general fashion only with big errors. This fact naturally also has an effect on the information content of neutron radiation attenuation calculations.

For approximation calculations on the attenuation of neutron radiation we can use an expression similar to the one connected with gamma radiation:

$$D_n = D_{0,n} \cdot 2^{-\frac{d}{d_{1/2}}} \qquad (5.17)$$

This gives us the attenuation factor m as follows:

$$m = \frac{D_n}{D_{0,n}} = \frac{1}{2^{\frac{d}{d_{1/2}}}} \qquad (5.18)$$

In calculating this half-life layer, we start with the following assumptions:

The annihilating effect of neutron radiation is primarily traced back to the fast and medium-fast neutrons with energies $E > 0.1$ MeV.

In substances that consist mostly of light elements (earth, wood, concrete, bricks), attenuation takes place mostly on the basis of elastic scatter.

In heavy elements (steel, lead) both the elastic and inelastic scatter must be considered because here the last-named process contributes decisively to the overall attenuation.

Table 5.3. Approximation Values for Half-Life Layers $d_{1/2}$ of Various Substances with Respect to the Neutron Radiation Deriving from a Nuclear Weapon Detonation

Substance	$d_{1/2}$	Substance	$d_{1/2}$
Water	3 cm	Earth	12 cm
Steel	4.5 cm	Concrete	12 cm
Lead	9 cm		
Wood	10 cm		

To conclude these considerations we might give an example: After an air burst of 20 kt, we get about 2,000 R gamma radiation and 1,000 rem neutron radiation at a distance of 1 km from the detonation center. From the values given for the half-layer (tables 5.2 and 5.3) we can estimate that, for example, 10 cm of steel will reveal an attenuation factor of 0.1 against gamma radiation and 0.2 against the neutrons.

This would give us effective nuclear radiation doses of 200 R and 250 rem, in other words, a total of 450 rem.

We can derive from this the fact that, first of all, the neutron dose in armored vehicles (without special neutron protection) can be above the value of the gamma radiation dose and, that, besides, neglecting the neutron dose in such cases would result in a very big mistake. The gamma radiation, appearing in conjunction with the inelastic scatter of neutrons, of course was neglected in this example.

5.3.3. Effect on Man Defense Possibilities

5.3.3.1. General Principles of Defense

In the case of nuclear weapon detonations with detonation intensities of $q < 50$ kt, the instantaneous nuclear radiation contributes considerably to the level of possible overall casualties among the troops.

The share of personnel damaged by instantaneous nuclear radiation, out of the total number of casualties, is very large, especially in the case of small detonation intensities when the troops are not in protected positions.

For example, in the case of $q = 50$ kt, it averages only about 5 percent whereas in the case of $q = 1$ kt it is up to 85 percent.[11]

These statistics tell us that much attention must be devoted to the attention of troops against the annihilating effects of instantaneous nuclear radiation.

In organizing unit defense against the annihilating effects of a nuclear weapon detonation one must keep in mind that the nuclear radiation doses of both components of instantaneous nuclear radiation--neutron radiation and gamma radiation--take effect practically within a span of just a few seconds completely or for the most part at the particular distances.

This means, in other words, that only that increase in the degree of shelter provided for personnel against instantaneous nuclear radiation can lead to a decisive reduction in losses which can be implemented immediately at the moment of detonation. Because individual protective clothing cannot bring about any noteworthy attenuation of instantaneous nuclear radiation in terms of its nature and purpose, one can only consider shelters of all kinds, combat vehicles, and the exploitation of the protective properties offered by the terrain when it comes to reducing the apparent nuclear radiation doses.

As we already stated rather generally in Section 5.3.2, closed shelter facilities offer equally good protection against both components of instantaneous nuclear radiation whereas the protective effect of open facilities, especially against neutron radiation, depends essentially on the particular angle of incidence of the radiation.

To increase the protective effect of armored vehicles against the neutron flux ($d_{1/2}$ gamma radiation for steel 2.8 cm, on the other $d_{1/2}$ neutron radiation 4.5 cm), we can expect the use of special absorber layers for neutrons in long-range terms.

Table 5.4 presents some attenuation factors for various types of shelters. It must be noted that other values apply to the attenuation of residual nuclear radiation. Certain protective properties can also be found in built-up, wooded, or heavily-cut terrain. But it is difficult to give binding numerical data for this. For example, the attenuation factor for gamma radiation in closely built-up towns is as much as 0.5. Basements in multi-story buildings reveal attenuation [protection] factors on the order of magnitude of 0.25 or 0.5 against gamma radiation or against neutron radiation.

Table 5.4. Average Value of Attenuation [Protection] Factors of Various Installations against Instantaneous Nuclear Radiation[12]

Type of shelters	Attenuation [protection] factor
Combat vehicles	
Trenches	0.25--0.1
Underbreastwork shelters	0.005--0.0025
Personnel shelters	0.0005--0.0003
Tanks and SP mounts	0.33--0.08

In the medical-biological field, possible protective measures against the effects of heavy radiation doses first of all reside in the preventive administration of certain radiation protection substances and, then, in the timely and comprehensive medical treatment of radiation victims after dose exposure.

But we cannot go into any greater detail on these problems here. In concluding our treatment of this question we might observe that total casualties due to instantaneous nuclear radiation exposure will reach its maximum about 4-6 hours after detonation.

5.3.3.2. Biological Effect of Instantaneous Nuclear Radiation--Conclusions for Unit Combat Capacity

The biological effect of instantaneous nuclear radiation, like the effect of nuclear radiation in general, is based primarily on ionization and excitations of atoms and molecules. Here, the action mechanism of nuclear radiation in the biological tissue is very complicated and some of the fundamental questions have still not been satisfactorily answered.[13]

Basically, ionized or excited molecules differ from those in the basic state by virtue of their physical or chemical properties. Because of that there will be frequently a decay of the molecules as a result of the energy transfer of nuclear radiation to the tissue through which radiation has passed. We get more or less chemically active decay products which can lead to the formation of alien compounds in the body and which thus have a toxic effect.

This means that irradiation so disturbs the biochemical processes in the organism that we first of all get disturbances in cellular metabolism, cell damage, followed by organ damage.

Figure 5.16 shows the basic development of cell damage due to nuclear radiation.

Figure 5.16. Possible course of cell damage due to nuclear radiation.[14]
Key: 1--Nuclear radiation; 2--Ionization, excitation, secondary radiation; 3--Indirect effect; 4--Direct effect; 5--Radiolysis of water, formation of free radicals; 6--Molecule change; 7--Ferment damage, above all that of nuclear metabolism; 8--Development of toxic metabolism products.

The character of anticipated radiation damage depends essentially on the radiation conditions.

This includes the following:

The magnitude of the nuclear radiation dose,

The type of nuclear radiation,

The duration of radiation or the level of the dose rate,

The magnitude and type of the radiated body volume and

The state of the organism as nuclear radiation takes effect.

Basically one can say that radiation damage will grow, the greater the absorbed nuclear radiation dose and the larger the radiated body share and the smaller the action time of nuclear radiation at identical dose. These interrelationships will now be observed somewhat more closely, including some problems involved in instantaneous and residual nuclear radiation. Further statements will be made in Chapter 7 regarding residual nuclear radiation.

The cumulative effects of radiation damage are expressed by the term "radiation sickness."

Table 5.5. Guidance Values for Probable Damage to Persons after One-Time Effect of a Certain Dose of Instantaneous Nuclear Radiation (1)

Dose (2) R	Degree of damage
0--50	No external indications of radiation damage, slight blood formation changes possible
50--100	About 5% of persons exposed to radiation will develop nausea and vomiting within 24 hours
100-150	About 20% of radiation victims will develop nausea and vomiting, 1st-degree radiation sickness
150--200	About 50% of radiation victims will develop nausea and vomiting, 1st-degree radiation sickness
200--250	About 75% of radiation victims will develop nausea and vomiting, 2nd-degree radiation sicknass
250--300	100% of radiation victims get sick; 2nd-degree radiation sickness, lethal outcome possible in 5% of cases
300-350	100% of radiation victims get sick; 3rd-degree radiation sickness lethal outcome to be expected for 20% of victims
400	Lethal outcome to be expected for 50% of victims (LD_{50})
600	Lethal outcome to be expected for 100% of victims (LD_{100})

(1) The values in the table can also be used for the evaluation of the anticipated radiation damage in case of action by similar doses of residual nuclear radiation if they are absorbed within 4 days.

(2) The dose values are to be interpreted exactly as rem values. But because in military terminology we practically use only the ion dose R, it is also given here. See also the statements in Section 5.1.1.

The magnitude of the absorbed radiation dose primarily determines not only the frequency of probable sicknesses and deaths but also the symptoms and the course of these sicknesses. In this kind of estimate one must however again restrictively consider the above-mentioned radiation conditions as a whole.

In general, one can distinguish somatic and genetic radiation damage or, according to a different approach, instant and late damage. Under military conditions we are primarily interested in instant damage which can lead to a loss of combat or action capacity.

Table 5.5 shows that, in case of short-time whole-body radiation, one must figure on the first casualties at a dose of 100 R. If there is no medical treatment, the lethal radiation doses for 50 percent or 100 percent of the victims will be 400 R or 600 R.

Table 5.6. General Overview of Symptoms of Radiation Sickness, Its Distinguishing Characteristics, and Its Course[14]

1st-degree radiation sickness	2nd-degree radiation sickness	3rd-degree radiation sickness
Dose 100--200 R	Dose 200--300 R	Dose 300--500 R
I. Initial period, period of primary reactions		
Symptoms:		
No vomiting on day of radiation exposure; nausea possible; weakness; slight susceptibility to fatigue	Vomiting on 1st day, decrease after several hours; weakness, slight susceptibility to fatigue; dizziness	Vomiting, possibly changing to loss of strength; difficulty breathing; possible diarrhea
Duration: 1-2 days		
II. Latency period, period of temporary well-being		
Symptoms:		
No symptoms	Slight weakness; minor difficulty in breathing after physical stress	Improvement in general condition; weakness, difficulty breathing during stress; lack of appetite; dizziness
Duration: 5-6 weeks	10-20 days	2-10 days

Table 5.6. [Continued]

III. Peak period, period of intoxication and infection

Symptoms		
General weakness; increased susceptibility to fatigue; lack of appetite	Increasing general weakness; severe susceptibility to fatigue, lack of appetite; angina; inflammation of mucosae in mouth; bleeding of skin and mucosae; infectious complications (starting with 3rd week), minor loss of hair	Sleepiness; loss of strength; flatulence; bloody slimy stool; cramps (from 8th-10th days on); angina; strongly pronounced inclination toward bleeding; pronounced hair loss; 39-41° body temperature; shortness of breath; without therapy, lethal outcome possible between 8th and 25th days

IV. Period of Convalescence

Symptoms		
Recovery; weakness symptoms sometimes possible	Improvement in general state; weakness up to 3 months; start of hair growth after about 40 days; slight relapse toward end of 3rd month mostly followed by recovery	Improvement in general state; continued slight susceptibility to fatigue; possibly repeated hair loss; complications (infections) possible
Overall degree of incapacitation:		
Up to 3 weeks at 100-150 R; more than 3 weeks at 150-200 R	2-3 months	3-8 months

One can consider 50 R to be the maximum permissible nuclear radiation dose from instantaneous nuclear radiation. The situation is different if, as in the case of residual nuclear radiation, the dose exposure extends over a longer period of time.

As we can see further from Table 5.5 we distinguish 1st, 2nd, and 3rd-degree radiation sickness depending upon the degree of radiation damage. These individual degrees of radiation sickness are primarily determined by the nuclear radiation dose absorbed and their course generally reveals four pronounced periods:

The initial period or period of primary reactions;

The latency period or period of temporary wellbeing;

The peak period or period of intoxication and infection;

The period of convalescence.

Table 5.6 presents a general overview of the symptoms, the distinguishing characteristics, and the course of the individual periods.

By way of summary we can say this:

The primary reactions during the initial period will appear all the faster and more pronounced, the greater the dose absorbed happens to have been. They thus permit certain conclusions as to the seriousness and the anticipated course of radiation sickness. These primary reactions need not necessarily lead to an immediate inability to fight. But that has nothing to do with the need for providing medical treatment as early as possible.

The latency period characterizes a period of apparent convalescence and is characterized by the absence or by only more or less strongly pronounced external disease phenomena. The sickness process itself however continues to develop. There now begins a decomposition of the blood and this is expressed especially in the reduction of the number of white blood corpuscles.

As we get into the peak period, there is a severe deterioration in the overall condition. Blood damage continues to progress. In case of combined injuries, wounds will heal extremely slowly. Numerous complications will arise in the course of the sickness due to vulnerability to infection.

The duration of the convalescence period will depend on the nuclear radiation dose absorbed and the general state of health prior to exposure to nuclear radiation. Additional damage due to the blast wave and light radiation also exert great influence. Individually major fluctuations develop in terms of time.

In describing some basic concepts and units of measure of gamma radiation and neutron radiation in Section 5.1.1, we already discussed the influence of the type of nuclear radiation on the character of anticipated radiation damage.

We can basically distinguish two action forms of nuclear radiation from radioactive substances:

The effect of nuclear radiation of those radioactive substances which are outside the body (outside radiation);

The effect of nuclear radiation of those radioactive substances which are inside the body (incorporation).

Instantaneous nuclear radiation constitutes this kind of outside radiation in which case the whole body is radiated through and practically all parts of the body are hit by an approximately equal nuclear radiation dose. (This

observation does not apply to the neutron doses. Here we get considerable differences between the sides of the body facing toward and facing away from the detonation.)

The difficulty encountered in the evaluation of damage caused by instantaneous nuclear radiation is based on the fact that the connection between the physical dose and the biological effect need not be clear.

For example, Hagen and Langendorf already pointed out that the biological effect of some nuclear radiation types, as that of the neutrons, is still not very well explored and that there are justified doubts as to whether the quality factors, recommended for the various neutron energies, reproduce the actual extent of anticipated damage within a commensurate error spread.[15]

This is why the problems connected with neutron dosimetry under field conditions are to be found not only in the area of physics in connection with the determination of the neutron spectrum appearing at the particular distances but also in the exact interpretation of the biological unit of measure called "rem."

In discussing the energy dose in Section 5.1.1.2, we already said that the connection between the doses in terms of Rad and rem is established via the particular quality factors. Some guidance values were given in Table 5.1.

These quality factors however are highly disputed because, basically, they apply only to certain biological reactions and a chromic radiation exposure. In case of one-time, short-term radiation, as represented by the instantaneous nuclear radiation from a nuclear weapon detonation, we obviously get smaller values for neutron radiation.

In addition to the magnitude of the nuclear radiation dose absorbed, the radiation time is of decisive significance for the casualty level due to radiation. One can basically say that identical nuclear radiation doses will cause different radiation damage in case of radiation with different dose rates.

Although this problem complex is of no significance in relation to instantaneous nuclear radiation, we might at this point go into the most important interrelationships here with a view to residual nuclear radiation.

There are two processes which take place simultaneously--damage and convalescence--as a result of the effect of nuclear radiation upon the organism.

While the first process depends on the magnitude of the radiation dose, the second process is determined by the time elapsed since radiation exposure and the speed of convalescence.

In other words, we are dealing here with the fact that the organism to a certain degree is in a position to restore its vital functions which were disturbed due to nuclear radiation. In this connection one can consider, as the particular effective biological dose, the dose whose effects have not yet

been overcome by the organism at the moment considered. On this problem complex, Blair established a theory of convalescence which among other things was further developed by Devidson for practical purposes.[16]

According to this theory, radiation damage develops in proportion to the intensity of radiation exposure while the processes of convalescence take place within certain limits at a speed that is proportional to the magnitude of this damage. A nonregenerable share of the damage is left behind and it is proportional to the magnitude of the total nuclear radiation dose absorbed.

It follows from a series of publications that the theoretical values, determined on the basis of this theory, agree with the experimental results.

The half-period of convalescence in man is assumed to be 29.75 days or 690 hours and that corresponds to a convalescence speed [rate] of 0.001 per hour.

For the nonregenerable part of radiation damage we use 10 percent of the summary [cumulative] dose.

Although the consideration of the particular effective biological dose under combat conditions is connected with a series of difficulties, Table 5.7 does present some numerical values for rough calculations.[17]

Table 5.7. Reference Values on Biologically Effective Dose as a Function of Time Elapsed since Radiation Exposure

(1) seit der Bestrahlung vergangene Zeit Wochen (3)	Abnahme (2) %	(1) seit der Bestrahlung vergangene Zeit Wochen	Abnahme (2) %
1	10	8	75
2	25	9	80
3	40	10	82
4	50	11	85
5	55	12	87
6	60	13	89
7	70	14	90

Key: 1--Time elapsed since radiation exposure; 2--Decrease; 3--Weeks.

The question as to the exact moment of loss of combat or operational capacity, following absorption of a certain nuclear radiation dose, is closely connected with the problems of radiation convalescence. The larger the absorbed nuclear radiation dose the faster will the moment of combat or operational incapacitation occur.

For instantaneous nuclear radiation, one can start with the following reference values for rough calculations:

In case of nuclear radiation doses on the order of magnitude of 5,000 R, there will be immediate incapacitation; at 1,000 R this will happen at the latest

after 1 hour; at 500-1,000 R this will happen within 1-4 hours; and at 250-500 R, this will take place within 1-2 days.

At doses of D < 250 R, 50 percent of the casualties will turn up within 1-4 days while the other 50 percent will turn up within 1-2 weeks. Table 5.8 presents more detailed data which can also be used for residual nuclear radiation.

Table 5.8 Reference Values for the Moment of Loss of Combat or Operational Capacity as a Function of the Time Interval during which Nuclear Radiation Dose Was Absorbed[18]

1 Dosis bei Einwirkung im Verlaufe von			Ausfall	davon fallen aus (%) nach Tagen 3							
4 24 Stunden	5 2~5 Tagen	6 6···10 Tagen	2 %	7 sofort	5	6	7	8	9	10	14
> 250	> 375	> 500	100	100							
200 ··· 250	300 ··· 375	400 ··· 500	50 ··· 100	50	10	10	10	10	10		
150 ··· 200	225 ··· 300	300 ··· 400	20 ··· 50	25			5	10	10		
100 ··· 150	150 ··· 225	200 ··· 300	5 ··· 20	10						10	
50 ··· 100	75 ··· 150	100 ··· 200	··· 5	2,5							2,5

Key: 1--Dose in case of exposure over a period of; 2--Loss; 3--Of that amount, the following (%) will be lost after the number of days given; 4--24 hours; 5--2-5 days; 6--6-10 days; 7--Immediately.

Note: The figures in the above table strictly speaking apply only to large numbers of casualties because there is a wide biological fluctuation spread in individual persons. The numerical values in the column headed "Immediate" are to be so interpreted that one must expect this loss rate during radiation exposure or at the latest upon reaching the dose figures given.

The individual types of cells and thus also the various tissues reveal differing degrees of sensitivity to nuclear radiation exposure.

In a simplified manner one can observe that especially those tissues are very sensitive to radiation which are quickly and constantly regenerated. If one furthermore considers the cell damage caused by radical formation, then that damage will increase, the more water-rich and oxygen-hungry a cell happens to be.

Regarding sensitivity, lymphatic tissues are at the head of the list while nerves and ganglia cells are at the end.

For example, lymphocytes will for the most part die at doses of 400-600 R while in the case of nerve cells only doses of around 3,000-6,000 R will bring about death.

This differing sensitivity means that especially the hematopoietic organs, the mucosae in the gastrointestinal tract, and the skin will be damaged primarily.

This is why as the result of radiation exposure it is not only the dose absorbed but also the magnitude and type of the radiated body volume which will be decisive for the anticipated radiation damage.

Basically we distinguish between whole-body and partial-body irradiation. Under combat conditions we are in fact interested only in whole-body irradiation for which the values given in the preceding tables also apply.

In conclusion we might say that the physical and psychological state of the particular individual can decisively influence the course and outcome of radiation sickness. Physically strong, healthy, and rested individuals can withstand a certain radiation exposure far better than weak, sick, or exhausted people. In addition we have the fact that, when troops are stationed out in the open, one must also expect combined damage due to several annihilation factors within the action radius of instantaneous nuclear radiation. In these cases, it is not only the course of radiation sickness which becomes more complicated but the sickness itself also on the other hand influences the healing of wounds, burns, etc. Many authors have pointed out that controlling shock plays a very big role in combined injuries. For example, Schumacher observed that, according to Japanese data, one out of every five persons with combined injuries suffered shock which can lead to states endangering human life.[19]

Table 5.9 presents an overview of the distances up to which, for certain detonation intensities, the various gradual degrees of damage can be expected due to instantaneous nuclear radiation. In interpreting these figures one must consider the aspects mentioned in this connection.

Table 5.9. Reference Values for Gradual Damage to Individuals Outside Shelters at Various Distances from Detonation Center due to Instantaneous Nuclear Radiation from Air or Ground Bursts

1 Detonationsstärke kt	2 Grad der Strahlungskrankheit		
	3 III. Grades	4 II. Grades	5 I. Grades
	6 Entfernung vom Detonationszentrum/m		
1	800	900	1000
10	1300	1400	1500
100	1800	1900	2100
1000	2500	2600	2800
10000	3400	3500	3700

Key: 1--Detonation intensity; 2--degree of radiation sickness; 3--3rd degree; 4--2nd degree; 5--1st degree; 6--Distance from detonation center, m.

Tabe 5.9 shows that, in case of small detonation intensities, the instantaneous nuclear radiation reveals considerable ranges. For example, the figure 1,000 m when q = 1 kt (1st-degree radiation sickness) is counterbalanced by

1,100 m in the case of light radiation (1st-degree burns) and 300 m for the blast wave (light injuries). This becomes even clearer when $q < 1$ kt. We can furthermore see that the gradual differences are very close to each other in terms of distance and that the range of instant nuclear radiation grows only slowly along with the increase in the detonation intensity compared to the other annihilation factors.

5.3.4. Effect on Electronic Structural Components and Other Materials and Increase in their Radiation Resistance

Instantaneous nuclear radiation from a nuclear weapon detonation leads to various types of radiation damage not only in living but also in inanimate substances. This damage is based on certain physical and chemical processes of a reversible or irreversible nature.

Earlier we said that such substance changes as a rule are blanked out by the annihilating effects of the blast wave and light radiation; this applies only to detonations in the dense layers of the atmosphere but certainly not to those at high altitudes. Here, instantaneous nuclear radiation plays a great role as an annihilation factor in defense against missiles and satellites.

This is why we will below take up some elementary problems of the effect of gamma and neutron radiation on various materials.

The effect of instantaneous nuclear radiation on electronic equipment is of particular interest here. Gamma and neutron radiation influences the electrical parameters of various structural elements and thus the function of entire subsystems and circuits.

At the moment of a nuclear weapon detonation, gamma radiation can knock out circuits working on pulse operation, it can lead to wrong responses in scanned circuits, it can lead to electrical breakdown, and it can alter the magnitude and shape of electrical signals.

According to available literature data one can estimate that electronic systems equipped with semiconductor elements will be knocked out if the fast neutron flux is on the order of magnitude of 10^{13} n cm^{-2}. Such values are attained at distances of several tens of kilometers from the detonation center in case of high-altitude detonations in the range of several megatons.

For gamma radiation, under identical conditions, the values of the critical dose rate for a series of important electrical circuits are on the order of magnitude of 10^7 R sec^{-1}; this corresponds to distances of several hundreds of kilometers from the detonation center.

In contrast to radiation in nuclear power plants, the properties of the substances and the parameters of the structural elements are practically momentarily altered because of the high nuclear radiation doses and the short action time of instantaneous nuclear radiation.

Ionization is among the best-known effects of gamma radiation (x-rays). The ionization of the air and other substances in electrical and electronic equipment increases the conductivity and can cause a decline in the breakdown voltage or the formation of ionization flows.

Gamma radiation furthermore leads to the decay of molecules in organic compounds and to the formation of free radicals which can be very active chemically. This results in chemical follow-up reactions of various kinds.

Organic polymeric dielectrics can be decomposed or gaseous constituents can be separated and they in turn are in a position to form acids with water (moisture) and to damage materials (corrosion of switches, relays, etc.).

Epoxyresins become soft and lose their dielectric properties. These last-named processes are irreversible, that is to say, they lead to permanent damage.

The neutron component of instantaneous nuclear radiation first of all leads to the disturbance of the crystal structure of various structural elements, to the formation of radionuclides, and also to ionization.

For example, the parameters of semiconductors can be altered because, due to the action of neutrons, neighboring atoms in the crystal lattice are shifted around or because induced foreign atoms are deposited in it [lattice].

Compared to gamma radiation, the ionizing effect of neutrons recedes and assumes a significant volume only in case of superfast neutrons ($E > 10$ MeV).

Summarizing we can say that metals (conductors), semiconductors, and nonconductors react very differently to high doses of instantaneous nuclear radiation. Semiconductors and some organic materials (artificial resins, lacquers, glues, impregnation and coating substances) are very sensitive; metals and inorganic nonconductors (glass, ceramics, quartz) are most resistant. In the case of glass, there can be clouding and discoloration due to nuclear radiation. But that requires gamma radiation doses of about 10^7 R or thermal neutron fluxes of about 10^{15} n cm^{-2}.

Even higher values (10^{20} n cm^{-2}) can finally also cause resistance [strength] changes in metals.

To protect electronic equipment and systems it is necessary to use radiation-resistant elements or those with high resistance to instantaneous nuclear radiation. Furthermore it is possible to protect particularly sensitive parts and subsystems by means of special screens or protective covers.

To prevent a response of circuits to pulse-shaped gamma components of instantaneous nuclear radiation, for example, in radar-controlled fuses, the latter must react correspondingly inertly or must be protected by discriminators.

Table 5.10. Maximum Permissible Nuclear Radiation Doses for Various Substances at which There Is a Reduction of no more than 25 Percent in Their Utility Properties[20]

	1 Werkstoff[1])	2 Neutronenstrom $n\ cm^{-2}$	3 Gammastrahlungsdosis R
4	Azetylzellulose (Papier)	$3 \cdot 10^{14} \cdots 2 \cdot 10^{15}$	$5 \cdot 10^{6} \cdots 4 \cdot 10^{7}$
5	organisches Glas	$10^{14} \cdots 10^{15}$	10^{5}
6	Phenolharze (ohne Harzträger)	$7 \cdot 10^{14}$	10^{7}
	Polyamide	$4 \cdot 10^{14}$	$7 \cdot 10^{6}$
	Polyvinylchloride	10^{15}	10^{6}
7	Polyterephthalsäureglykolester	10^{15}	10^{7}
8	Organosiliziumöl	$7 \cdot 10^{13} \cdots 3 \cdot 10^{14}$	$(1 \cdots 5) \cdot 10^{6}$
9	Phenolharze mit organischem Harzträger	10^{16}	10^{8}
	Polyäthylene	10^{17}	10^{8}
10	Glasfasergewebe	10^{16}	10^{8}
11	Epoxidlacke	–	$(5 \cdots 10) \cdot 10^{8}$
12	Keramik	$3 \cdot 10^{20}$	$5 \cdot 10^{12}$
13	Glas	10^{18}	$3 \cdot 10^{9}$
14	Quarz	10^{19}	10^{10}
15	Glasglimmer (Mikalex)	10^{19}	10^{11}
16	Glimmer	10^{18}	10^{10}
17	Polystyrol	$2 \cdot 10^{19}$	$5 \cdot 10^{9}$

Key: 1--Material (1); 2--Neutron flux; 3--Gamma radiation dose; 4--Acetylcellulose (paper); 5--Organic glass; 6--Phenolresins (without resin carrier); 7--Polyterephthalic acid glycol esters; 8--Organic silicon oil; 9--Phenolresins with organic resin carrier; 10--Glass fiber fabrics; 11--Epoxide lacquers; 12--Ceramic; 13--Glass; 14--Quartz; 15--Glass-mica (Mikalex); 16--Mica; 17--Polystyrene; (1) The values in the table were determined at an intensity of 10^{11} to 10^{12} neutrons $cm^{-2}\ sec^{-1}$ and a gamma radiation dose rate of 10^{6} to 10^{7} R hr^{-1}.

Review Questions

5.12. What basic effects can one expect due to the influence of instantaneous nuclear radiation in living and inanimate substances?

5.13. Explain the reciprocal action processes of gamma radiation with a substance (photo effect, Compton effect, pair formation effect).

5.14. Explain the most important reciprocal action processes of neutrons with a substance (elastic and inelastic scatter, neutron capture).

5.15. What laws constitute the basis of the attenuation of gamma radiation and neutron radiation? Derive the corresponding conclusions for that regarding protection for units.

5.16. What is the practical significance of work with half-life layers? What must be observed concerning the information content of the calculations?

5.17. Memorize the values of important half-life layers.

5.18. What conclusions do you draw from the differing attenuation capacity of individual substances with respect to gamma radiation and neutron radiation? Explain your finding with the help of some examples.

5.19. Summarize the most important measures for protecting units against the annihilating effect of instantaneous nuclear radiation.

5.20. In your own words, express the biological effects of instantaneous nuclear radiation (nuclear radiation).

5.21. What factors determine the character of possible radiation damage in man after nuclear weapon detonations?

5.22. Why is it not a good idea to specify "maximum permissible radiation doses" for instantaneous nuclear radiation?

5.23. Does the possible appearance of a latency period of radiation sickness lead to any conclusions regarding the evaluation of unit combat and operational readiness?

5.24. Wherein do the most essential differences in radiation conditions reside in the case of outside radiation and incorporation?

5.25. What do we mean by the term "radiation convalescence?" Does the consideration of "biological fading" of a nuclear radiation dose absorbed under combat conditions have any great meaning?

5.26. Is it possible--if the dose absorbed is known--to determine the exact moment of loss of combat readiness in units directly hit?

5.27. Why do high doses of instantaneous nuclear radiation have a strong effect especially on the way in which electronic equipment and systems work?

5.28. Why is guaranteeing the reliable functioning of electron systems with respect to instantaneous nuclear radiation primarily a "purely technical problem?"

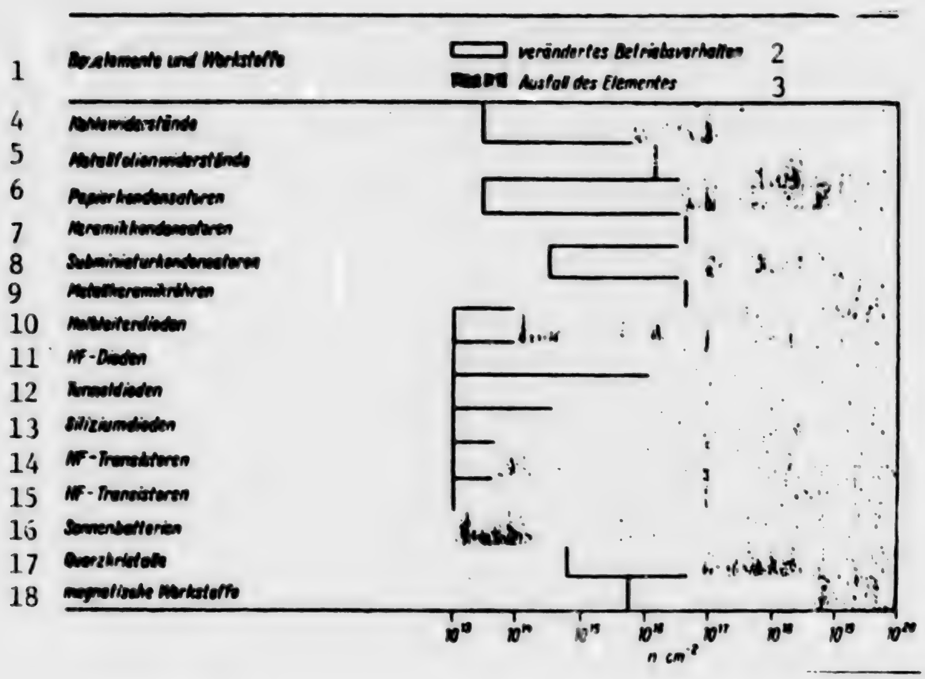


Figure 5.17. Influence of neutrons (E > 10 keV) on the way in which various structural components work.[21]

Key: 1--Structural components and materials; 2--Altered operational performance; 3--Loss of component; 4--Carbon resisters; 5--Metal foil resisters; 6--Paper condensers; 7--Ceramics condensers; 8--Subminiature condensers; 9--Metal ceramic tubes; 10--Semiconductor diodes; 11--HF diodes; 12--Tunnel diodes; 13--Silicon diodes; 14-- LF transistors; 15--HF transistors; 16--Solar batteries; 17--Quartz crystals; 18--Magnetic working materials.

5.4. Notes for Chapter 5

1. On these questions compare the following: "Decree on Protection against the Damaging Effect of Ionizing Radiation--Radiation Protection Decree," dated 18 December 1969, GESETZBLATT DER DDR [Legal Gazette of the GDR], Part II, No 99, pp 627 ff.

2. It is pointed out here that the terms "radiation dose" and "ray dose" are generally customary.

3. See also Padelt, E., and H. Laporte, "Einheiten und Groessenarten der Naturwissenschaften," VEB Technical Book Publishing House, Leipzig, 1967, p 148 and p 257.

4. It emerges from Table 5.1 that the QF factors are only rough guidance values. In this connection it is noted that, in the derivation of the biological dose called rem, the relationship dose in rem = dose in rep · RBW was also used. According to Padelt, p 257, the rep unit is defined as follows: The Roentgen-equivalent-physical is the (absorbed) quantity of any (nuclear) radiation which, in 1 kg of air will release an energy of $83.8 \cdot 10^{-4}$ Joule, which in 1 kg of animal tissue will

release an energy of $94 \cdot 10^{-4}$ Joule, and which physically will produce the same effect as 1 roentgen.
1 roentgen-equivalent-physical = 0.838 Rad
1 rep = 0.838 Rad
Because these computations however are only rough calculations, the same QF factors can be used in both cases.

5. There is still a certain inconsistency in the use of dose units at this time. In the case of gamma radiation, the roentgen is used as the unit of the ion dose; on the other hand, the rem is used for neutron radiation as a unit derived via the energy dose.

   For practical considerations, it is however possible in the case of gamma radiation numerically to equate R and rem. But for the cumulative gamma and neutron dose we must use the unit rem.

6. Figure 5.2 was taken from Lavrenchik, V. N., "Global'noye vypadeniye produktov yadernykh vzryvov," Atomizdat, Moscow, 1965, p 17.

7. See also Gurevich, I. I., and K. N. Mukhin, "Atomnaya energiya," 1957, Appendix I, quoted from Lavrenchik, V. N., loc. cit., p 17.

8. The nomograms in Figures 5.4 and 5.5 were copied from "The Effect of Nuclear Weapons," Washington, 1962, Russian edition of the above-named work available from USSR Defense Ministry Publishing House, Moscow, 1965, pp 363 and 364.

9. See also Yampol'skiy, P. A., "Neytrony atomnogo vzryva," Gozatomizdat, Moscow, 1961.

10. The nomogram was taken from "The Effects of Nuclear Weapons," loc. cit., p 376.

11. See also DV-36/2, MfNV, 1966, p 23.

12. The table was taken unchanged from DV-36/2, p 22.

13. On this problem complex see also Pink V., "Biological Effect of Ionizing Rays," NVA Information Service, Military Medicine Series, 1971, 5, pp 5 ff.

14. Prepared after a special supplement entitled "Strahlenschaeder" [Ray Damage] of the control office of military-medical information and documentation, Ernst Moritz Arndt University, Greifswald, 1967.

15. See Hagen, U., and H. Langendorf, "On the Question of Using the Biological Dose Value 'rem' for Radiation Protection," ATOMKERNENERGIE [Atomic Nuclear Energy], 5, 1960, 5, pp 173-181.

16. Blair, H. A., Atomic Energy Project, N.W., 13 May and 3 July 1952; Devidson, G. O., "Biological Consequences of General Gamma Irradiation

in Man," Atomizdat Publishing House, Moscow, 1960, Russian.

17. A detailed and summarizing presentation of this problem complex can be found among others in Petrov, R. V., and others, "Protection against Radioactive Fallout," Medgiz Publishing House, Moscow, 1963, Russian.

18. Special supplement "Strahlenschaeden," loc. cit., p 4.

19. Further details on this question can be found in Schumacher, K., "The Effect of Nuclear Weapons on the Human Organism and the Health and Medical Supply of Victims," Publication Series of the DRK [German Red Cross] of the GDR, 1960.

20. The table was taken unchanged from Chyprin, Yu., "Radio Engineering Working Materials under the Effect of Neutron and Gamma Radiation," TEKHNIKA I VOORUZHENIYE, 1968, 10, p 11.

21. The description was taken from Chuprin, Yu., "In the Radiation Field," TEKHNIKA I VOORUZENIYE, 1968, 12, p 14.

6. Electromagnetic Impulse from Nuclear Weapon Detonation and the Change in Certain Properties of the Atmosphere after High-Altitude Bursts

6.1. General Description of Electromagnetic Impulse

Nuclear weapon detonations are accompanied by various electromagnetic phenomena which have been known for quite some time but which are increasingly the subject of general interest due to the growing "electronization of the armies."

One of the most important phenomena is the electromagnetic impulse.

There are various causes for the origin of electromagnetic impulses from nuclear weapon detonation. But in the final analysis all of them can be traced back to the sudden production and asymmetrical distribution of large quantities of electrical charge carriers.[2]

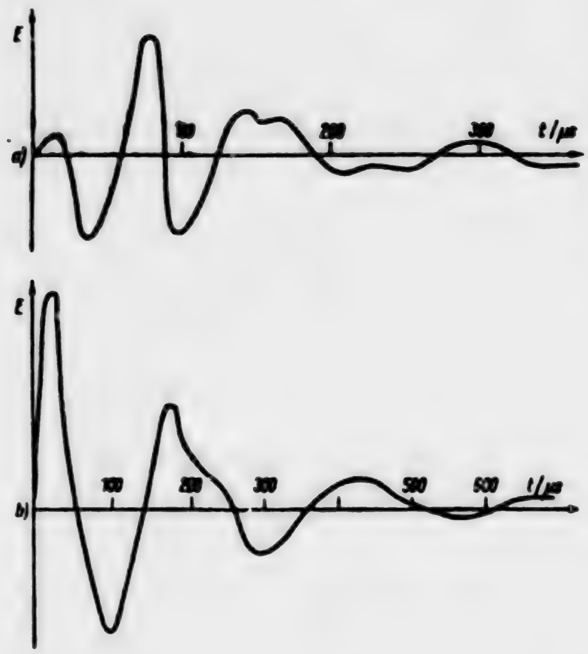


Figure 6.1. Comparison of "signals" produced by a nuclear weapon detonation and an atmospheric discharge.[1]
a--"Signal" of nuclear weapon detonation recorded at a distance of 3,000 km from the detonation center; b--"Signal" of a bolt of lightning received at a distance of 1,000 km.

In all nuclear weapon detonation, one source of the electromagnetic impulse is the heavy ionization of the air by the gamma component of instantaneous nuclear radiation. In case of high-altitude detonations, another source is the reciprocal effect of the highly ionized plasma of the detonation products with the earth's magnetic field.

The heavy ionization of the air in the case of nuclear weapon detonations does not remain confined only to the immediate fireball but, in case of detonations in the dense layers of the atmosphere, additionally covers a region with a thickness of several hundred meters around the fireball.

The gamma quantums, spreading to all sides from the detonation center, enter into a reciprocal action with the atoms and molecules in the air and transmit a large part of their energy to them. Here, the Compton effect predominates by far.

The energy-rich Compton electrons likewise move away from the detonation center at high speed. As a result of this there is a first current impulse and a relative shift or division of the negative and positive charges because the ionized atoms and molecules in fact remain on the spot. A radical electrical field is built up.

If the propagation of the electrons were to be based on complete spherical symmetry, then the external overall effect of the electromagnetic field would be equal to zero because the effect of each charged oscillating particle would again be cancelled out by the effect of the symmetrical particle which is opposite to it. This kind of symmetry however does not exist for various reasons.

The asymmetry in the propagation of the Compton electrons and thus also in the shape of the electromagnetic field results from the particular structure of the nuclear charge, the screening effect of the earth's surface, and the uneven air density in the individual directions. This is why the asymmetrical distribution of the electrons works as a short-time, directed charge impulse which, similar to an electrical dipole, radiates high-frequency energy which makes up the first part of the electromagnetic impulse of a nuclear weapon detonation.

The fast Compton electrons on their way lead to a secondary ionization; that is to say, we again get free electrons although with less energy. These free electrons begin to move toward the detonation center under the influence of the electrical primary field. They bring about a second current [flow] impulse and the buildup of a second electromagnetic field opposite to the first one. This process supplies the second part of the electromagnetic impulse of a nuclear weapon detonation. Its action time is shorter than that of the first part because the slower secondary electrons are recombined faster. These processes are repeated several times until a complete charge equalization has been achieved.

(There is no simple neutralization of the electromagnetic fields; this, in a simplified explanation, is due to the fact that many electrons are deposited along electrically neutral atoms and molecules as a result of which the process of complete recombination is delayed.)

Summarizing, we can say:

At the moment of a nuclear weapon detonation, pulsating electromagnetic fields and electrical currents are formed in the atmosphere and in the ground [earth] which, during their existence, emit electromagnetic waves of varying frequency.

Because of their short action time--it is something between microseconds and milliseconds--we speak of the electromagnetic impulse of a nuclear weapon detonation.

Its destructive effects are determined by the maximum field intensity (amplitude), the magnitude of the change in the field intensity with the passage of time, and the spectral composition of the emitted electromagnetic waves.

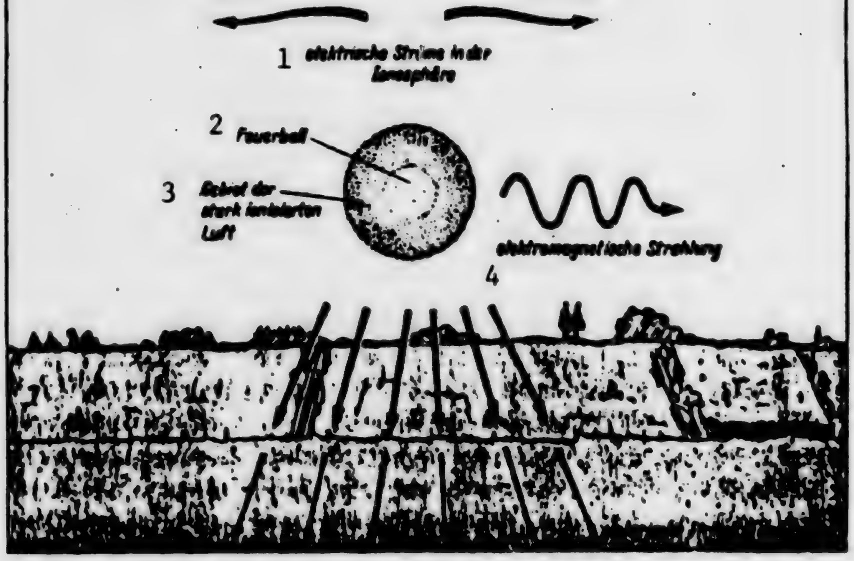


Figure 6.2. Origin of electromagnetic fields and electrical currents [fluxes] after nuclear weapon detonation.[3] Key: 1--Electrical currents in the ionosphere; 2--Fireball; 3--Region of heavily ionized air; 4--Electromagnetic radiation.

The electromagnetic impulse reveals a very broad frequency spectrum. According to data by Langhans[4], the ascent time of the primary impulse is about 10^{-8} so that the maximum frequencies will be around 100 Mhz. Electromagnetic waves with this kind of high frequency however are quickly absorbed as they are propagated in the atmosphere. This is why most of the energy share is concentrated in the low-frequency range of about 10-30 kHz.

The intensity and action time of the electromagnetic impulse rise relatively slowly with increasing detonation intensity.

The type of detonation essentially influences the duration of the impulse. In the case of ground and air bursts, the duration of the impulse is on the order of magnitude of several hundred microseconds up to several milliseconds; in the case of high-altitude bursts, it can take effect for several hundreds of milliseconds.

Review Questions

6.1. What are the fundamental properties of the electromagnetic impulse from a nuclear weapon detonation?

6.2. Can one draw initial conclusions from the observation that the electromagnetic impulse resembles atmospheric discharges--conclusions as to its basic effect and the required protective measures?

6.3. Why, in explaining the causes of the origin of the electromagnetic impulse, do we place such great value on the understanding of the significance of the assymmetrical charge distribution?

6.2. Propagation of Electromagnetic Impulse as a Function of Detonation Conditions

Depending on the detonation conditions, the electromagnetic impulse can spread over great distances. Here it is first of all suitable as a phenomenon in proving the existence of detonations; besides, the great field intensity values at shorter distances also will cause certain damage to electrical systems.

After ground bursts and low-altitude air bursts, the electromagnetic field is polarized vertically. Due to its effect there is an induction of electrical currents--which are directed radially from ground zero--not only in the air but also on the ground.

According to data by Flambard, the area of ground zero was marked with a metal carpet in connection with a French nuclear weapon test. This carpet was connected with a remote ground [earth plate] by means of a strong conductor. Under these conditions, a current peak value of 150,000 amperes was measured.[5]

According to available literature data, the annihilating or damaging effect of the electromagnetic impulse after detonations near the ground is confined to distances of several kilometers but can exceed the corresponding radii of the effect of the blast wave and light radiation. In this range, the field intensity amplitudes in the air can reach several tens of thousands of volt m^{-1} and in the earth they can reach 100-1,000 v m^{-1}. As the distance from ground zero increases, the amplitude values drop quickly.

Figure 6.3 shows some field intensity values as a function of the detonation intensity and the distance from the detonation center.[6]

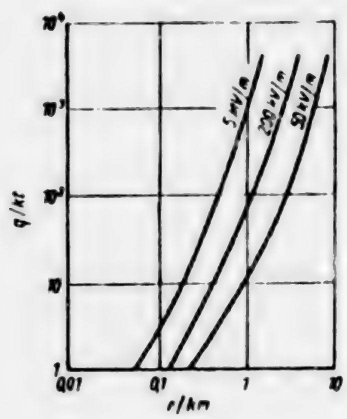


Figure 6.3. Reference values for field intensities of the electromagnetic impulse appearing after nuclear weapon detonations.

After air bursts we basically get the same phenomena as after ground bursts but the level of the field intensity amplitude drops quickly as the detonation altitude grows. Likewise, the currents produced in the ground are diminished due to the severe attenuation.

After underground and underwater detonations, there is practically no need to consider the propagation of the electromagnetic impulse in relation to the overall effects of the other annihilation factors.

Entirely different conditions for the propagation of the electromagnetic impulse result from high-altitude detonations outside the dense atmosphere. Here the electromagnetic impulse consists of two pronounced phases whereby especially the reciprocal effect of the ionizing plasma of the detonation products with the earth's magnetic field contributes to a powerful impulse during the second phase.

This is due to the fact that the free electrons, formed during ionization, in case of low air density, have long and free path distances (100-1,000 m) and perform spiral movements due to the action of the earth's magnetic field along the force lines. Here, a part of their kinetic energy is reflected [radiated away] in the form of electromagnetic waves (braking radiation).[7] According to various data, we are still supposed to be able to get maximum field intensity values on the order of magnitude of 100 kV m^{-1} after high-altitude detonations even at distances of several hundreds of kilometers from the detonation centers.

Review Questions

6.4. Explain the influence of detonation conditions on the propagation of the electromagnetic impulse of a nuclear weapon detonation.

6.5. What conclusions result from the fact that the electromagnetic impulse can induce powerful currents and fields also in the earth?

6.3. Annihilating Effects of Electromagnetic Impulse and Protection against Them

The electromagnetic impulse from a nuclear weapon detonation can damage radio, telephone, television, radar, as well as EDP equipment and systems, it can temporarily put out of action electric power plants and power supply systems, and it can also injure the people who operate them.

The damaging effects of the electromagnetic impulse are primarily based on the fact that it induces high voltages in all conductors with large linear dimensions with respect to the earth and these high voltages in turn can trigger short-time, sudden current surges.

This is why the electromagnetic impulse has a strong effect especially on overhead lines, underground cables, telephone lines, signal lines, etc. in that--due to the high overvoltages, as a function of the impulse resistance of the cables, lines, and equipment--the insulations are punctured, fuses and conductors are melted, semiconductor components are destroyed, and magnetic working materials are rendered useless.

Furthermore, we must anticipate the start of fires in electronic instruments. This shows that the electromagnetic impulse can greatly influence the system of wire communications. On the other hand, its direct effect on radio communications is far less. It is expressed only for fractions of seconds in the form of an interference impulse, similar to atmospheric disturbances, and can furthermore cause relatively low input voltages in radio sets. In

this connection we must not fail to mention the possible influence of the electromagnetic impulse on the operation of data processing systems.

The probability of the appearance of induction currents depends extensively on the shape of the electromagnetic impulse, that is to say, on the time change in the field intensity. On the other hand, the magnitude of induced voltages and thus also of the currents is determined by the maximum field intensity appearing at the particular distance from the detonation center.

One must furthermore keep in mind that not the entire spectrum contributes equally to the induction of voltages and currents. Instead, frequencies of several kHz are decisive here primarily.

It is especially this part of the overall spectrum which becomes weaker particularly quickly upon the propagation of electromagnetic waves in the air and in the ground. This is why the annihilating effect of the electromagnetic impulse remains confined to several kilometers after ground and air bursts.

The magnitude of the voltage induced in a conductor is a complex function of the detonation intensity, the length of the conductor or the amplifier field, the distance from the detonation center, the direction of the conductor in relation to ground zero, the detonation altitude, and other factors. This is why generalizable statements are difficult to make. We might therefore present some numerical data taken from Jastak here.[8] Accordingly, overvoltages of several hundreds of thousands of volts can appear between overhead lines. The overvoltages between a ground cable and the ground themselves are several hundred times greater than between the individual cable strands. Telecommunications systems are exposed to the heaviest stresses. The maximum stressability for DC is assumed to be 4 kv.

For the electromagnetic impulse on the other hand we generally get an impulse strength of 10 kv and in case of a lightning rod system we have a figure of as much as 50 kv.

Most resistant are high-voltage lines with impulse strengths of several hundred kilovolts (see Figure 6.3). But nuclear weapon detonations at high altitudes, because of the extremely high field intensity values, can, at these altitudes likewise, induce voltages of several hundred kilovolts up to distances of 100 km and more from the detonation center and thus damage them.

Weather conditions greatly influence the impulse strength [resistance]. In case of rain or wet weather, this resistance can drop for instance by as much as one order of magnitude.

From the problems we have taken up so far we can clearly see that, among others, much attention must be devoted to the protection of communications equipment against the damaging effects of the electromagnetic impulse from nuclear weapon detonations for the sake of providing steady communications.

In a simplified manner one might assume that this involves questions similar to protection against lightning. In reality, the implementation of protection against the electromagnetic impulse turns out to be much more complicated because we are dealing here not only with the protection of transmission systems but also with all of the pertinent lines, in other words, the entire system as a whole.

The most important protective measures for lines and cables include the following:

Basic laying of symmetrical two-conductor systems which are well insulated against the ground;

Underground cables which consist of several conductors of identical electrical capacity must be laid in metal pipes to reduce possible overvoltages between the cable and the ground to a minimum;

Attainment of short amplifier field lengths, that is to say, limitation of voltage and current peaks, due to the installation of protective systems (current and voltage fuses) which will quickly be regenerated automatically in order to achieve short interrupter times;

Good grounding of shieldings.

The following requirements must be added for the protection of instruments and systems:

Installation of special protective circuits;

Continuous grounding of instruments;

Lining of cabins and workrooms, in which electronic and electrical instruments are installed, with rubber mats or other insulating materials;

Carrying out fire protection requirements.

For special protection for human beings it is necessary to avoid contact with metal parts, for example, the housings of communications equipment. Under certain circumstances one may also have to wear protective gloves.

Summarizing we can say here that the most important requirements for protection against the annihilating effects of the electromagnetic impulse from a nuclear weapon detonation must be considered and implemented during the design and construction of the particular equipment and systems.

Review Questions

6.6. What are the physical processes to which one can trace the annihilating or damaging effects of the electric magnetic impulse?

6.7. What are the factors that determine or influence the magnitude of the voltages and currents in the conductors?

6.8. Why must both current and voltage fuses be built in as protective systems?

6.9. By means of what measures can one guarantee steady communications even when the enemy uses nuclear weapons?

6.4. Influence of High-Altitude Detonations on Radio Wave Propagation

The properties of the earth's atmosphere change as the altitude increases not only due to the steadily declining air density but also due to the increase in the degree of ionization due the action of solar radiation. As we know, the ionosphere, which starts at an altitude range of about 50 km consists of several layers of increased ionization whose location is not exactly determined.

In the lowest layer, the D layer, in an altitude spread of 50-80 km, the average free path of charged particles (electrons and protons) is so great that constant ionization is maintained during the day. At the same time however the density of the neutral particles is still so high that there are frequent collisions.

Electromagnetic waves of a certain frequency, while passing through this layer, transfer a part of their energy first of all to the free electrons which the latter then again pass on to neutral atoms and molecules during collision.

Between 80 km and 130 km, we have the E layer in which ionization is even stronger than in the D layer and in which the electromagnetic waves are absorbed considerably less.

The F layer begins above 130 km. In it, the lifetime of the free electrons is so long that ionization remains preserved also at night.

This differing ionization in the individual altitude layers, briefly sketched here, brings about the refraction of the radio waves in the upper atmosphere, that is to say, the partial reflection of the space wave toward the earth's surface.

The influence of high-altitude detonations on the propagation of the radio waves basically consists in the fact that they lead to an additional, extraordinarily strong ionization in the particular ranges. X-rays and the UV part of the light spectrum also contribute to this, in addition to instantaneous nuclear radiation and residual nuclear radiation.

Flambard[9] presents a summarizing discussion of this problem complex.

In case of detonation altitudes below 15 km, the zone of strong ionization is limited to the fireball as such and several hundred meters around it. Because of the high air density, there is recombination after records. The

effects on the propagation of electromagnetic waves therefore are brief in terms of time and are limited in terms of space.

The radioactive detonation products, rising with the fireball or the detonation cloud, among other things emit gamma radiation which, in the rarefied air, can spread upward to very great altitudes and which under certain circumstances can reach the ionosphere's D layer where it brings about an additional ionization that can last hours.

In case of detonation altitudes between 15 km and 65 km, the ionization is increased due to the effect of primary radiation (gamma and neutron component of instantaneous nuclear radiation, x-rays, UV radiation) in the entire part of the D layer which is in the direct field of vision of the detonation center, up to the limitations resulting from the earth's curvature.

The rising fireball carries the radioactive detonation products to even greater altitudes, the products are distributed over a region with a diameter of as much as several hundred kilometers, and the gamma radiation emitted covers distances of several thousand kilometers.

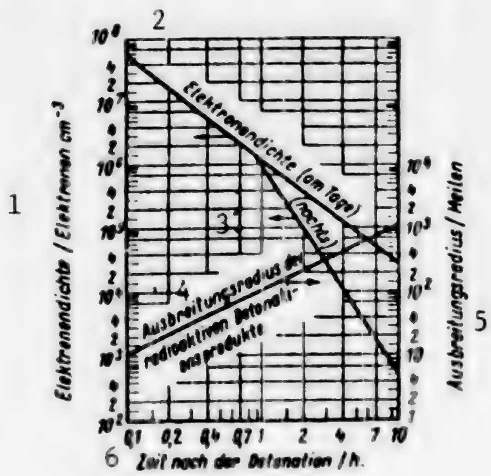


Figure 6.4. Propagation radius of radioactive detonation products and electron density in the area of the D layer as a function of the time for an 1-Mt nuclear weapon detonation in an altitude range of 15-65 km.[10]
Key: 1--Electron density, electrons cm^{-3}; 2--Electron density (daytime); 3--Night; 4--Propagation radius of radioactive detonation products; 5--Propagation radius, miles; 6--Time after detonation, hrs.

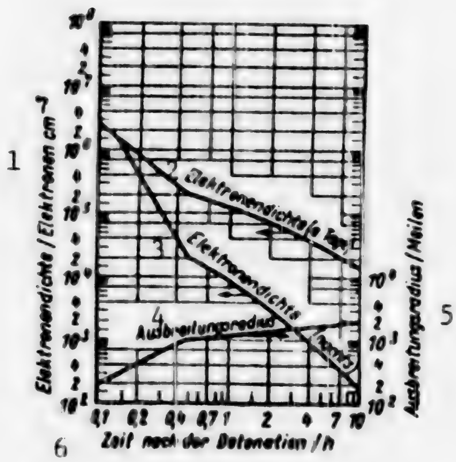


Figure 6.5. Propagation radius of radioactive detonation products and electron density in the area of the D layer as a function of the time for a 1-Mt nuclear weapon detonation in an altitude range of 65-110 km.[11]
Key: 1--Electron density, electrons cm^{-3}; 2--Electron density, daytime; 3--Electron density, night-time; 4--Propagation radius; 5--Propagation radius, miles; 6--Time after detonation, hrs.

In case of nuclear weapon detonations at altitudes of more than 65 km, the ionization caused by primary radiation immediately spreads over the entire D layer to the extent that the earth's curvature so permits.

The fireball and the radioactive detonation products are flung to altitudes of several hundred kilometers. They take up vast spaces and cause ionization processes here (see Figure 6.5).

In this connection there are reciprocal action processes between the free electrons and the earth's magnetic field which will be described below in a brief and elementary fashion.

In keeping with the laws of electrodynamics, the electrons, released during ionization--if they are expelled from the electron envelopes of the atoms at an initial velocity whose vector within certain limits forms an angle with the earth's magnetic field--describe spiral movements along the force lines which act as "guidelines." Because the intensity of the earth's magnetic field reaches its particular maximum where the force line hits the earth's surface (conjugated magnetic points), the angle between the velocity vector and the direction of the magnetic field will keep growing as the electrons approach the earth's surface.

Assuming that this angle finally gets to be 90°, before the electrons are absorbed by the denser layers of the atmosphere, the electrons can finally be deflected and in this way can oscillate between two extreme mirror or reflection points. These electron movements take place at velocities on the order of magnitude of 1,000 km/sec^{-1}.

Because the electrons captured by the magnetic field reveal different velocities and because the earth's magnetic field is subjected to intensity changes in terms of time and space, we finally observe the development of artificial radiation belts whose existence in terms of time, depending on the altitude, into which the electrons are "fired," can extend for months and even years.

It has been calculated that, if only 1/10 of the energy of a nuclear weapon with a detonation intensity of 1 Mt is consumed for ionization in case of detonation outside the atmosphere's dense layers, the latter would form 10^{32} free electrons--just as many as are already present in the normal ionosphere; this is why, under these detonation conditions, there is practically the creation of an artificial ionosphere.[12]

The regions of increased ionization, caused by nuclear weapon detonations, influence the propagation of radio waves, interfere with existing radio communications, and impair the operation of radar stations. The reflection capacity of regions with increased ionization depends on their location, their electron density, and the frequency and angle of incidence of the radio waves.

Depending on the prevailing electron density, we get maximum frequencies (boundary frequencies) which are barely just reflected. Higher-frequency radio waves will penetrate the particular ionosphere layer. The higher the

electron density, the higher is also the corresponding boundary frequency. Because signals in the frequency range of 3-30 kHz are transmitted due to reflection between the earth's surface and the lower boundary of the ionosphere, the influence of nuclear weapon detonations is small here.

In case of transmissions in the LF and MF region (30-300 kHz or 300 kHz to 3 MHz), the propagation condition for space waves can be quite different.

Signals in the HF range (3-30 MHz) can be completely absorbed or heavily attenuated upon passing through the D layer in case of increased ionization. This effect can last several seconds. In addition we have the possible influence on the propagation of radio waves at this frequency due to hydrodynamic movements in the ionosphere.[14]

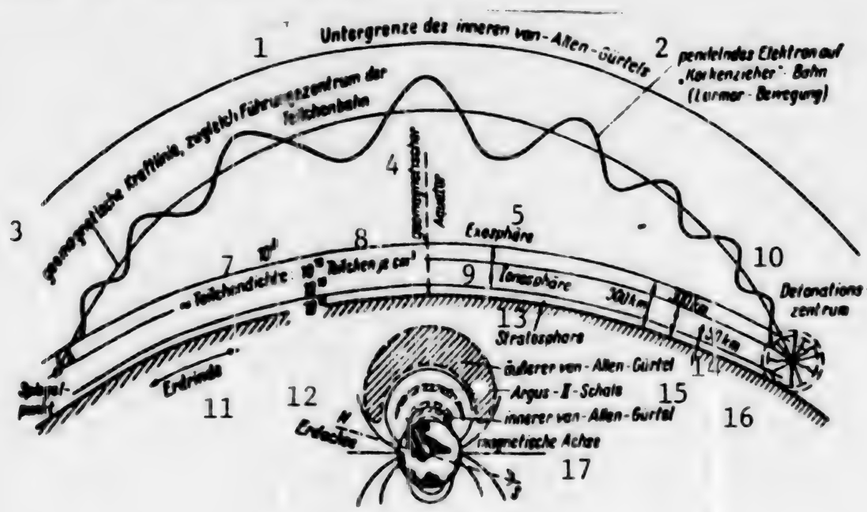


Figure 6.6. Sketch explaining the origin of artificial radiation belts as a result of nuclear weapon detonations outside the dense atmosphere according to Langhans.[13] Key: 1--Lower boundary of the inner van Allen belt; 2--Pendulating electron on "corkscrew" path (Larmor movement); 3--Geomagnetic power line, at the same time control center for particle path; 4--Geomagnetic Equator; 5--Exosphere; 6--Mirror point; 7--Particle density; 8--Particle per cm^3; 9--Ionosphere; 10--Detonation center; 11--Earth's crust; 12--Earth's axis; 13--Stratosphere; 14--Outer van Allen belt; 15--Argos I [illegible] shell; 16--Inner van Allen belt; 17--Magnetic axis.

The influence of artificial regions with increased ionization on the propagation of radar pulses as a rule is less than in the case of radio waves so long as the radar unit and the target are also below the ionosphere.[15]

In case of systems which work in the decameter range, the impulses can be considerably weakened and destroyed. That can lead to the wrong measurements.

In case of systems working in the centimeter and millimeter wave range, the radioactive detonation clouds produce echoes which among other things can be used for nuclear weapon detonometry.

Summarizing we can say that the differing propagation conditions for electromagnetic waves (radio waves) due to high-altitude detonations must be constantly registered and analyzed. By optimizing radio communications and through the selection of the best frequency ranges it is possible even in such complicated situations to guarantee unit command.

Review Questions

6.10. What factors lead to the development of heavily ionized regions after high-altitude detonations?

6.11. Explain the basic processes which, in case of nuclear weapon detonations outside the dense atmosphere, lead to the formation of artificial radiation belts.

6.12. What is the influence of changes in the ionosphere on the propagation of radio waves? Draw conclusions from this regarding the maintenance of stable unit communications.

6.5. Notes for Chapter 6

1. The picture was taken from Flambard, A., "Nuclear Explosions and Telecommunications" REVUE DE DEFENSE NATIONAL [National Defense Review], 1966, 2, p 330.

2. See also Langhans, K., "Kernwaffenradiometrie und Kernwaffendetonometrie," German Military Publishing House, Berlin, 1970, pp 398 ff.

3. The photo was taken from Jastak, Z., "The Electromagnetic Impulse--Fifth Annihilation Factor from Nuclear Weapon Detonation," PRZEGLAD WOJSK LADOWYCH, 13, 1971, 7, p 103.

4. Langhans, K., "Kernwaffenradiometrie...," loc. cit., p 401.

5. Flambard, A., "Nuclear Explosions...," loc. cit., p 334.

6. Petre, S., "Handbuch der Waffenwirkungen fuer die Bemessung von Schutzbauten" [Handbook of Weapons Effects in Dimensioning Shelters], Federal Civil Defense Bureau, Bern, 1964, p 241.

7. Section 6.4 contains further details on this problem complex.

8. Jastak, Z., "The Electromagnetic Impulse...," loc. cit.

9. Flambard, A., "Nuclear Explosions...," loc. cit. pp 332 ff.

10. The photo was taken from "The Effects of Nuclear Weapons," Washington, 1962, Russian edition of the above-named work available from USSR Defense Ministry Publishing House, Moscow, 1965, p 500.

11. Ibid.

12. To investigate these processes, the United States particularly in 1958 and 1962 conducted series of tests, as follows: 1958, Johnston Island, "Teak," 1 August, megaton range, detonation altitude 70 km; "Orange," 12 August, megaton range, detonation altitude 40 km; 1958, South Atlantic, from the vessel "Norton Sound," "Argus I to III," 27 August, 30 August, 6 September, 2 kt, each, detonation altitude each time 480 km; 1962, Johnston Island, 9 July, 1 Mt, detonation altitude 400 km; 20 October, 20 kt, detonation altitude 50 km; 26 October, intensity unknown, detonation altitude between 30 and 50 km; 1 November, 1 Mt, detonation altitude 50 km; 4 November, low detonation intensity, altitude unknown.

13. The photo was taken from Langhans, K., "Kernwaffenradiometrie ...," loc. cit., p 405.

14. By the term "hydrodynamic wave" we mean the phenomenon to the effect that, in case of detonations at high altitudes, most of the atmosphere can be carried away over distances of several thousand kilometers by the collision front resulting during the detonation.

15. Concerning this problem complex see also Taeumer, F., and E. Starik, "On the Influence of Nuclear Weapon Detonations in the Atomosphere on the Propagation of Radio Waves," MILITAERWESEN, 9, 1965, 1, pp 91-108 and 2, pp 234-256; Kienert, M., "What Are the Effects of Nuclear Weapon Detonations on Radio and Radar?" MILITAERTECHNIK, 6, 1966, 11, pp 413-415.

7. Residual Nuclear Radiation from Nuclear Weapon Detonation

7.1. General Description of Radioactive Detonation Products

The radioactive contamination of the earth, the air, and the water resulting from nuclear weapon detonations--hereafter briefly called radioactive terrain contamination--is determined or influenced by very many factors. Here one must distinguish between the factors on which the quantity and properties of the developing radioactive detonation products depend and those which influence their propagation and distribution.

The residual nuclear radiation emitted by radioactive detonation products is an annihilation factor especially after ground bursts, underground detonations, and in some cases also low-altitude air bursts which can considerably influence unit operations for days and weeks and in the near and further detonation area and in the direction in which the detonation cloud moves off. This is why the term "nuclear radiation situation" was defined in this context.[1]

In judging the overall problem complex, which units face during combat operations in large areas of radioactively contaminated terrain, it is from the very beginning important to evaluate the quantity and quality of radioactive detonation products. Here one must keep in mind that radioactive

terrain contamination can be traced back not only exclusively to nuclear fission weapons but that radioactive contamination after detonations of nuclear synthesis weapons and multi-phase weapons must be included in our considerations.

In general, radioactive detonation products from nuclear weapon detonations consist of three radiation sources: fission products, neutron-induced radioactivity, and the unfissioned part of the nuclear charge.

Regardless of the fact that these three sources are not homogeneous in themselves, the percentage share, which each of them contributes to the overall radioactivity after a certain detonation, can change on the basis of the particular construction of the nuclear weapon and the specific detonation conditions.

This is why it would be necessary to estimate the orders of magnitude of the sources of residual nuclear radiation mentioned at least for the most important nuclear weapon types. On the other hand we have the fact that data on the detailed structure of nuclear weapons, above all about the share of the individual phases of energy release out of the total energy, can hardly ever be found in accessible literature. In order nevertheless to give a certain idea, Table 7.1 compares the initial radioactivities of radioactive detonation products from a 20-kt nuclear weapon detonation based on nuclear fission and 20-Mt multi-phase nuclear weapon detonation.[2]

Table 7.1. Orders of Magnitude of Initial Radioactivities after 20-kt (Nuclear Fission) and 20-Mt (Nuclear Fission--Nuclear Synthesis--Nuclear Fission) Detonation

Detonation intensity	Initial radioactivity, Ci	
	20 kt	20 Mt
Fission products (Pu-239)	$2 \cdot 10^{12}$	$5 \cdot 10^{13}$
Fission products (U-238)	-	$1.75 \cdot 10^{15}$
Neutron-induced radioactivity (1)	$2 \cdot 10^{9}$	$2.8 \cdot 10^{12}$
Unfissioned nuclear charge (Pu-239)	$2.4 \cdot 10^{2}$	$6 \cdot 10^{3}$
Unfissioned nuclear charge (U-238)	-	1.5

(1) The values given for neutron-induced radioactivity relate to an underground detonation; that is to say, they thus represent the particular upper boundary value.

7.1.1. Fission Products

Nuclear fission as the basis of energy release in nuclear weapons was covered earlier in Section 1.3.1. There we also pointed out that the nuclear fragments, the fission products, which develop during the fission of the particular nuclear explosive, are radioactive.

As nuclear explosives (fissile materials) as we know, we consider in the case of nuclear weapons essentially the nuclides U-233, U-235, Pu-239 as well as Th-232 and U-238.

Following the detonation of a nuclear weapon with an intensity of 1 kt, an energy amount of $E_{Det} = 2.5 \cdot 10^{25}$ MeV is released (see Section 1.3.2.1). In the release of this energy due to nuclear fission--assuming that an energy of 200 MeV is produced for each split nucleus--that would be equivalent to $1.3 \cdot 10^{23}$ nuclear fissions per kiloton of detonation energy.

Out of the total energy of 200 MeV per split nucleus, on the average of 23 MeV are released during the course of the radioactive decay of the fission product. Of that, about 6 MeV (26 percent) are taken up by gamma radiation, 7 MeV (30 percent) by beta radiation, and 10 MeV (44 percent) by the neutrinos emitted during beta decay processes.

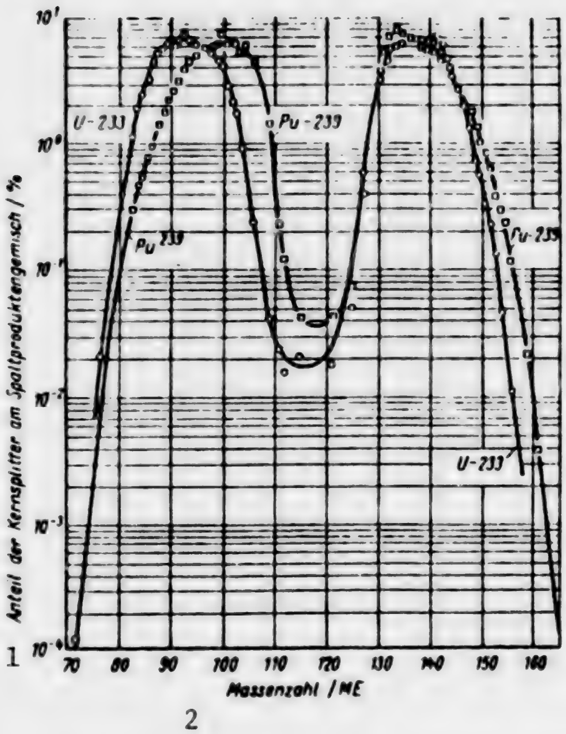


Figure 7.1. Shares of nuclear fragments out of fission product mixture as function of mass number for U-233 and Pu-239 in case of fission due to thermal neutrons.[5]
Key: 1--Share of nuclear fragments out of fission product mixture, %; 2--Mass number, ME.

The initial activity of fission products (1 min after detonation) per kiloton of detonation energy is on the order of magnitude of 10^{11} Ci.

The fission products are a mixture of various radioactive substances whose physical and chemical properties and biological effects result from the "sum" of the properties of the individual radionuclides.

The composition of the fission product mixture changes constantly with the passage of time after the detonation due to the differing half-life figures for the individual radionuclides; this is why its properties also change parallel to this process.

The composition of the fission product mixture basically depends on the nuclear explosive used and the energy of the neutrons exciting nuclear fission.[3] Table 7.2 presents a rough overview of the quantitative yield from the fission of Th-232, U-235, U-238, and Pu-239 by neutrons with a certain energy.[4]

The share of the various nuclear fragments out of the fission products mixture is subject to a certain distribution law (see Figure 7.1).

As we can see from Figure 7.1, we get very essential differences (up to two orders of magnitude) from fission due to thermal neutrons in the share of nuclear fragments out of the fission product mixture for U-233 and Pu-239 especially in the range of mass number A = 105 to A = 115.

In case of unsymmetrical nuclear fission, the maximum frequency of the formation of nuclear fragments is in the range of the mass numbers A = 95 and A = 140.

As the neutron energy increases, the share of symmetrical nuclear fragments grows (see Table 7.2).

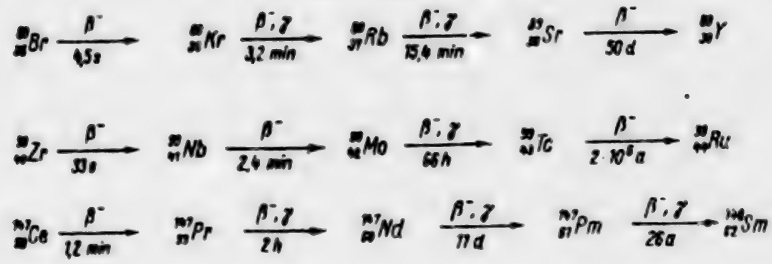


Figure 7.2. Examples for decay series of radioactive fission products.

In general we can say that nuclear fission produces a mixture of about 60 radionuclides of 35 chemical elements whose mass numbers are between A = 70 and A = 160.

Because a decay series follows every radionuclide produced during nuclear fission--each initial nuclide is subject to an average of two or three nucleus conversions until it reaches a stable final nucleus--the fission product mixture encompasses about 200 radionuclides in the end.

The decay series formed by beta conversions are characterized by the fact that, as a rule, the half-life of the follow-up nuclide is longer than that of the preceding one while the proportionally average maximum energy of beta radiation reveals a declining tendency because the longer-lived radionuclides on the average emit a softer beta radiation than the short-lived ones. Figure 7.2 gives some examples of the decay series.

Table 7.2. Yield of Fission Products (%) from the Fission of U-235, Pu-239, U-238, and Th-232 by Neutrons of Varying Energy

Kern-splitter 9	Spaltung durch Spaltneutronen 10			11	Spaltung durch Neutronen mit einer Energie $E = 14$ MeV 12		Spaltung durch Synthese-neutronen
	U-235	Pu-239	U-238	Th-232	U-235	U-238	U-238
1	2	3	4	5	6	7	8
Zn-72				$3{,}3 \cdot 10^{-4}$			
Ga-73				$4{,}5 \cdot 10^{-4}$			
Ge-77				$9 \cdot 10^{-3}$			
Br-82					$4 \cdot 10^{-3}$		
Br-83	0,23	0,059	0,24	1,9	1,16	0,62	
Kr-83			0,40	1,99			
Br-84	0,62	0,19	0,82		1,87	1,1	
Kr-84			0,85	3,65			
Kr-85	0,25	0,07	0,15	0,87	0,42	0,25	
Kr-86			1,38	6,0			
Sr-89	4,15	1,44	2,9	6,7	4,5	2,7	2,93
Sr-90	5,0	2,2	3,2	6,8	4,5	3,1	3,5
Y-91	5,2	2,69	3,68	7,2	6,4	3,7	3,65
Y-93	5,38	3,64	4,64		4,91	4,5	
Zr-95	6,72	5,12	5,7		5,0	5,2	5,17
Zr-97	6,5	5,2	5,4	5,2	4,5	5,8	
Mo-99	6,1	6,0	6,3	2,7	5,17	5,7	5,9
Mo-101	6,0	6,0	6,3		4,2	5,5	
Mo-102						3,9	
Ru-103	3,9	6,0	6,6	0,16	3,5	4,9	
Ru-105	1,0	4,7	4,4		1,8	2,3	
Rh-105				0,07	1,7	3,4	
Ru-106	0,5	5,2	2,7	0,04	1,58	3,11	
Pd-109	0,15	2,0	0,32	0,06	1,31	1,2	
Ag-111	0,07	0,55	0,08	0,05	1,20	0,96	
Pd-112	0,04	0,14	0,05	0,06	0,81	0,69	
Ag-113	0,04	0,17	0,04		1,1	0,85	
Cd-115^{m}			0,01	0,01	0,06	0,06	
Cd-115	0,04	0,07	0,03	0,07	1,0	0,64	
Sn-121					1,23	0,96	
Sb-125	0,06	0,12	0,02		0,64	0,48	
Sb-127	0,26	0,62	0,12		2,28	1,7	
Sb-129	0,79	1,78	0,88		2,6	1,4	
J-131	3,11	4,85	3,33	1,2	4,3	4,8	

[Continued on following page]

Table 7.2. [Continued from preceding page]

Kern-splitter 9	Spaltung durch Spaltneutronen 10			11	Spaltung durch Neutronen mit einer Energie E = 14 MeV 12		Spaltung durch Synthese-neutronen
	U-235	Pu-239	U-238	Th-232	U-235	U-238	U-238
1	2	3	4	5	6	7	8
Xe-131			3,2	1,62	4,3		
Te-132	4,4	6,3	4,7	2,4	4,2	4,7	
J-132					5,0		
Xe-132			4,7	2,87	5,0		
J-133	6,0	6,2	5,7		5,4		
J-134	1,3	1,4	1,1		5,3		
Xe-134			6,6	5,38	5,9		
J-135	6,0	5,6	5,8		4,5		
Xe-135						5,5	
Cs-135			6,0		5,7		
Xe-136			5,9	5,65			
Cs-136					0,23		
Cs-137	6,3	6,8	6,2	6,3	5,1	5,7	5,76
Ba-139	6,2	5,3	6,1		5,0	4,6	
Ba-140	5,8	5,0	5,7	6,2	4,6	4,6	4,88
Ce-141	5,3	4,65	5,62	9,0	4,47	4,45	
Ce-143					3,9	3,6	
Pr-143						3,2	
Ce-144	5,0	3,7	4,5	7,1	3,3	3,3	4,42
Nd-147	2,3	2,5	2,6		1,8	2,0	2,87
Pm-149	1,1		1,8				
Sm-153	0,21	0,48	0,41		0,24	0,39	
Tb-161	$4{,}6 \cdot 10^{-4}$		$1{,}6 \cdot 10^{-3}$				

Key: 9--Nuclear fragments; 10--Fission due to fission neutrons; 11--Fission due to neutrons with an energy of E = 14 Mev; 12--Fission due to synthesis neutron.

The fission products are beta-active and beta-gamma-active. The half-life of the radionuclides extends from fractions of seconds up to 200,000 years (Tc-99). During the first phase after the detonation, it is especially the short-lived nuclides which contribute decisively to overall radioactivity (instantaneous and residual nuclear radiation); but later on they as a matter of fact drop out of the fission product mixture.

As we can see in Figure 7.3, the relative radioactivity components produced by the individual radionuclides rise to a certain maximum and then decline again. In this way, the fission products are increasingly enriched with long-lived nuclides.

Table 7.3 presents an overview of some of the properties of important radionuclides (nuclear fragments and daughter products).[7]

The following among others will change during the process of decay of radioactive detonation products:

The summary [cumulative] radioactivity;

The cumulative dose rate;

The cumulative average energy of gamma and beta radiation;

The ratio between beta particles and gamma quantums emitted per decay process.

The decline in summary [cumulative] radioactivity of fission products with the passage of time after nuclear weapon detonations follows a simple law which was formulated for the first time in 1948 by Way and Wigner.[8]

$$A(t) = A_0 \left(\frac{t}{t_0}\right)^n \qquad (7.1)$$

Whereby the values for n will vary in the range of (-1.12) to (-1.45) as a function of the time elapsed since the detonation.

For the first few days and weeks, we can with sufficient accuracy figure on the average value of $n = -1.2$.

Levochkin and Sokolov proved that, in the case of fission products from U-235 and Pu-239, the maximum deviation of the radioactivity from the values calculated according to the $t^{-1.2}$ law over a period of a year will be no more than 40 percent.[9]

For fission products from U-238, Petrov gives an average value of $n = -1.3$ for the calculation of the decline in radioactivity over a period of time of up to 2 weeks after the detonation and thereafter, up to 3 months, he gives a value of $x = -1.5$.[10]

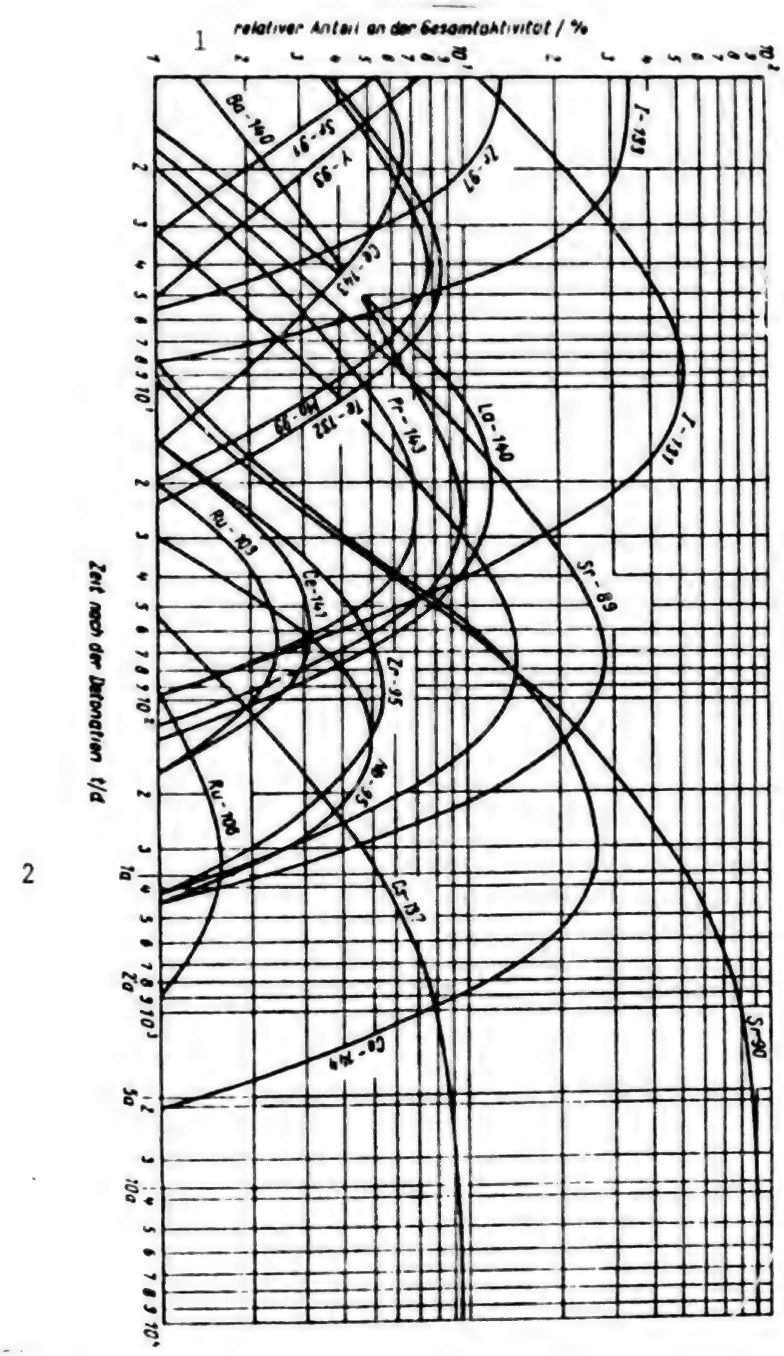


Figure 7.3. Change in relative share of fission products of some important radionuclides as a function of the time.[6] Key: 1--Relative share out of total radioactivity, %; 2--Time after detonation, t, d.

Table 7.3. Characteristic Data on Important Radionuclides of the Fission Product Mixture from a Nuclear Weapon Detonation

	1 Radionuklid	Symbol	2 Strahlungs-typ	3 Halbwert-zeit	$E_{\beta(max)}$ / MeV	4 $E_{\beta(mittel)}$ / MeV
	Krypton-85	$^{85}_{36}$Kr	β^-, γ	9,4 a	0,7	0,22
	Strontium-89	$^{89}_{38}$Sr	β^-	53 d	1,5	0,57
	Strontium-90	$^{90}_{38}$Sr	β^-	19,9 a	0,5	0,20
	Zirkonium-95	$^{95}_{40}$Zr	β^-, γ	66 d	0,9	0,17
10	Molybdän-99	$^{99}_{42}$Mo	β^-, γ	67 h	1,2	1,1
	Ruthenium-103	$^{103}_{44}$Ru	β^-, γ	42 d	0,25	0,07
	Ruthenium-106	$^{106}_{44}$Ru	β^-	1,0 a	0,04	0,01
	Jod-131	$^{131}_{53}$J	β^-, γ	8 d	0,6	0,21
	Xenon-133	$^{133}_{54}$X	β^-, γ	5,3 d	0,3	0,01
11	Cäsium-137	$^{137}_{55}$Cs	β^-, γ	33 a	0,6	0,18
12	Barium-140	$^{140}_{56}$Ba	β^-, γ	12,8 d	0,8	0,27
	Cer-141	$^{141}_{58}$Ce	β^-, γ	30 d	0,5	0,15
13	Neodym-147	$^{147}_{60}$Nd	β^-, γ	11 d	0,7	0,26

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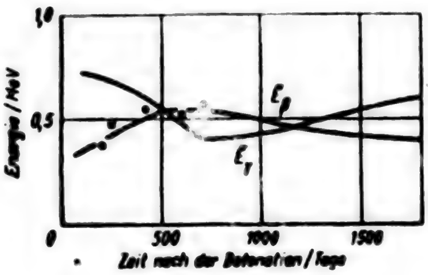
Table 7.3. [Continued from preceding page]

E_γ / MeV 5	Anteil der Gammaquanten je Zerfallsprozeß/%	6 Angaben zum Verhalten bei Inkorporation		
		kritische Organe 7	biologische Halbwertzeit 8	effektive Halbwertzeit 9
0,54	0,65	–	–	–
–	–	14 Knochen	49 a	51 d
		15 Gesamtkörper	35 a	50,3 d
–	–	14 Knochen	49 a	18 a
		15 Gesamtkörper	35 a	16 a
0,72	99	14 Knochen	3 a	61 d
0,23	1	16 Nieren, Milz	2,5 a	60 d
		15 Gesamtkörper	1,2 a	56 d
0,18	97,5			
0,78	2,5	14 Knochen	150 d	2,8 d
0,74	17,5			
		17 Muskeln	12 d	9 d
0,50	96	16 Nieren, Leber	16 d	12 d
		14 Knochen	0,5 a	30 d
		15 Gesamtkörper	16 d	12 d
–	–	17 Muskeln	12 d	11,5 d
		16 Nieren, Leber	16 d	15 d
		14 Knochen	0,5 a	0,4 a
		15 Gesamtkörper	16 d	15 d
0,37	81	18 Schilddrüse	140 d	8 d
		15 Gesamtkörper	138 d	7,6 d
0,08	36	–	–	–
		17 Muskeln	140 d	138 d
0,66	92	19 Leber	90 d	89 d
		14 Knochen	140 d	138 d
		15 Gesamtkörper	70 d	40 d
0,54	30	14 Knochen	65 d	11 d
0,03	100			
0,16	70	15 Gesamtkörper	65 d	11 d
		14 Knochen	4 a	31 d
0,15	67	19 Leber	0,8 a	29 d
		20 Nieren	1,6 a	30 d
		15 Gesamtkörper	1,6 a	30 d
0,09	60	14 Knochen	4 a	11 d
0,32	15	19 Leber	130 d	10 d
0,53	25	20 Nieren	1,8 a	11 d
		15 Gesamtkörper	1,8 a	11 d

Key: 1--Radionuclides; 2--Radiation type; 3--Half-life; 4--Average; 5--Share of gamma quantums per decay process, %; 6--Data on response in case of incorporation; 7--Critical organs; 8--Biological half-life; 9--Effective half-life; 10--Molybdenum-99; 11--Cesium-137; 12--Barium-140; 13--Neodymium-147; 14--Bones; 15--Whole body; 16--Kidneys, spleen; 17--Muscles; 18--Pancreas; 19--Liver; 20--Kidneys.

1



2

Figure 7.4. Change in average energy of beta and gamma radiation of fission products during time interval of up to 1,500 days following detonation.[12] Key: 1--Energy, Mev; 2--Time after detonation, days.

The dose rate and the cumulative energy of gamma radiation of fission products are directly proportional to each other but their ratio changes with the passage of time.

If we furthermore assume proportionality between the change of the cumulative radioactivity of the fission products and the cumulative dose rate (see Table 7.4), then it follows, in analogy to Formula 7.1, that we have, for the decline in the dose rate with the passage of time after detonation:

$$P(t) = P_0 \left(\frac{t}{t_0}\right)^n \qquad (7.2)$$

whereby however for the exponent we find applicable the value n = -1.2 with adequate accuracy only for a period of time of up to 10 days following the detonation.

Because times t > 10 days play a subordinate role for investigations under field conditions, we might make reference at this point only to the data in Table 7.5.[11]

For resolving a series of practical questions of unit protection against the annihilating effects of residual nuclear radiation in conjunction with operations in radioactively contaminated areas (nuclear radiation monitoring, dosimetry, estimating protected properties offered by combat vehicles and facilities) it is necessary to know the change in the energy of gamma and beta radiation from fission products during the passage of time after nuclear weapon detonations.

The graph in Figure 7.4 presents a rough overview.

Figure 7.5 shows additional values, broken in detail for the time interval of up to 10 days after detonation. Here it must however be kept in mind that the average maximum energy of beta radiation has been plotted.

Table 7.4. Cumulative Radioactivity of Fission Products (U-235) and Cumulative Energy of Gamma Radiation as a Function of the Time

1	Zeit nach der Kernwaffendetonation			
	1 h	7 h	1 d	2 d
$\Sigma A / Z\ s^{-1}\ kt^{-1}$	$1{,}5 \cdot 10^{19}$	$1{,}7 \cdot 10^{18}$	$4{,}4 \cdot 10^{17}$	$1{,}7 \cdot 10^{17}$
$\Sigma E\gamma$ /MeV $s^{-1}\ kt^{-1}$	$9{,}0 \cdot 10^{18}$	$8{,}0 \cdot 10^{17}$	$2{,}0 \cdot 10^{17}$	$9{,}1 \cdot 10^{16}$
$\Sigma A : \Sigma E\gamma$	1,7	2,1	2,2	1,9
	4 d	7 d	10 d	20 d
$\Sigma A / Z\ s^{-1}\ kt^{-1}$	$7{,}3 \cdot 10^{16}$	$4{,}0 \cdot 10^{16}$	$2{,}9 \cdot 10^{16}$	$1{,}5 \cdot 10^{16}$
$\Sigma E\gamma$ /MeV $s^{-1}\ kt^{-1}$	$3{,}6 \cdot 10^{16}$	$2{,}2 \cdot 10^{16}$	$1{,}5 \cdot 10^{16}$	$7{,}3 \cdot 10^{15}$
$\Sigma A : \Sigma E\gamma$	2,0	1,8	1,9	2,1
	30 d	100 d		
$\Sigma A / Z\ s^{-1}\ kt^{-1}$	$9{,}2 \cdot 10^{15}$	$2{,}4 \cdot 10^{15}$		
$\Sigma E\gamma$ /MeV $s^{-1}\ kt^{-1}$	$4{,}4 \cdot 10^{15}$	$7{,}9 \cdot 10^{14}$		
$\Sigma A : \Sigma E\gamma$	2,1	3,0		

Key: 1--Time after nuclear weapon detonation; h--hr.

Table 7.5. Average Values of the Exponent n to Calculate the Fading of the Dose Rate of Fission Products as a Function of the Time after Detonation

1 Zeit nach der Detonation	n
1 min $< t <$ 30 min	−0,89
30 min $\leq t <$ 1 d	−1,11
1 d $\leq t <$ 4 d	−1,25
4 d $\leq t <$ 3 a	−1,60
3 a $\leq t <$ 20 a	−0,35
20 a $\leq t <$ 50 a	−1,0
50 a $\leq t <$ 100 a	−2,0

Key: 1--Time after detonation.

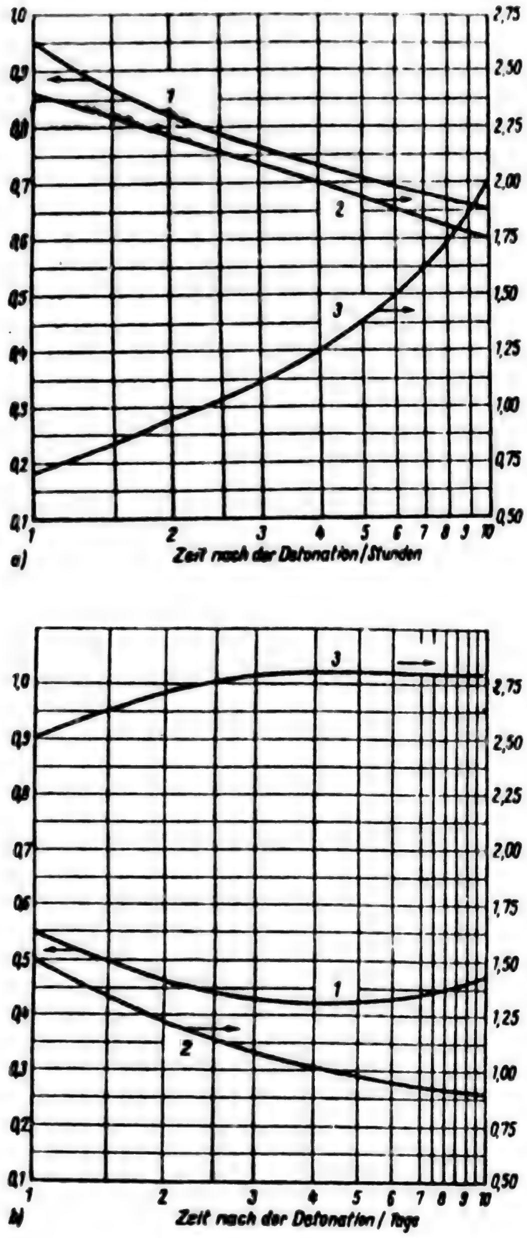


Figure 7.5. Change in average maximum energy of beta radiation and average energy of gamma radiation as well as average dose constant of gamma radiation of fission products for the first 10 days after detonation+.
a--1-10 hours after detonation; b--1-10 days after detonation
+1--Average energy of gamma radiation, MeV; 2--Average maximum energy of beta radiation, MeV; 3--Dose constant of gamma radiation of fission products, R cm^2 h^{-1} mCi^{-1}.
(To get the dose constant in the customary unit of R m^2 h^{-1} Ci^{-1}, the values in the table must be multiplied with the factor 10^{-1}. The unit of measure mentioned results from the double use of the scale subdivision.)
Key: 1--Time after detonation, hours; 2--Time after detonation, days.

Figure 7.5 shows that one can figure on an average gamma radiation energy value of 0.7 MeV during a period of 1-10 hours following the detonation. For a subsequent interval of up to 10 days, an average value of 0.5 MeV indicates the gamma radiation energy with adequate accuracy.[13] The average maximum energy of beta radiation from fission products between 1 and 10 hours after the detonation is 2 MeV (average energy 0.7 MeV) and between 1 and 10 days it is 1.2 MeV (average energy 0.35 MeV).

For radiation calculations under field conditions, especially for problems of radiation protection in shelters, Spencer points out that it turns out to be best to use the gamma radiation spectrum of the fission products 1 hour

after the detonation as basis. This view is justified by saying that, first of all, the essential share of the effective nuclear radiation dose comes from the first few hours after detonation and, besides, the spectrum of gamma radiation from fission products 1 hour after detonation characterizes the penetrating properties of gamma radiation rather well also for those of a different age.

This gamma spectrum is illustrated in Figure 7.6 also for a comparison of the spectrums 1 day and 10 days after detonation.[14]

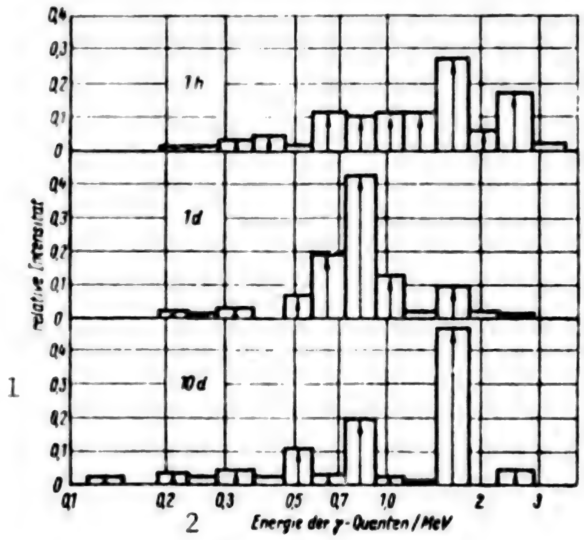


Figure 7.6. Relative intensity of spectral components of gamma radiation of fission product mixture at various times after detonation. (In the drawing, the height of each rectangle is in proportion of gamma radiation of that energy interval out of the total spectrum whereby the arrows drawn are the energy characteristics assumed for the calculation of the given interval. Gaseous fission products are not considered here). Key: 1--Relative intensity; 2--Energy of gamma quantums, MeV.

Along with the change in the composition of the fission product mixture during the passage of time after detonation there is also a change in the average ratio of the beta particles and gamma quantums emitted per decay process. This ratio--for fission products which originated during the fission of U-235 by means of thermal neutrons--is based on Bjoernerstedt and is indicated in Figure 7.7.[15]

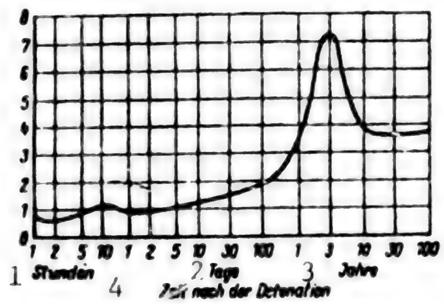


Figure 7.7. Average ratio of beta particles and gamma quantums, emitted per decay process, as function of the time after a nuclear weapon detonation. Key: 1--Hours; 2--Days; 3--Years; 4--Time after detonation.

We may assume that similar ratios result from the fission of other nuclear explosives due to fast neutrons.

The illustration shows that, up to 5 days following the detonation, the ratio between the beta particles and the gamma quantums emitted per decay process is below or at 1, whereas after 100 days it has a value of 2, keeps growing and 3 years after the detonation reaches a maximum of about 7. This means, in other words, that during this period of time, the relative share of gamma radiation out of the cumulative energy declines constantly as the age of the fission products increases.

7.1.2. Neutron-Induced Radioactivity

While the quantity and properties of radioactive fission products developing after nuclear weapon detonations can be estimated with adequate accuracy, this is not readily the case regarding neutron-induced radioactivity, briefly also called induced radioactivity.

This is above all due to the fact that, in addition to the influence of the design and makeup of the particular nuclear weapon, and here again especially the type of energy release, the type of nuclear weapon detonation and the nature of the detonation area also have an extraordinarily strong effect. This results not only in certain difficulties in the evaluation of the scope of anticipated induced radioactivity, for example, the estimate of radioactive terrain contamination in the area of a low-altitude air burst, but also in the interpretation and further processing of corresponding measurement values.

Regardless of that we can say that both concerning the overall radioactivity induced after nuclear weapon detonations, and the size of the surface areas which are thus radioactively contaminated, we get considerable differences compared to radioactive contamination from fission products. As the data in Table 7.1 already clearly indicated, the values of neutron-induced radioactivity are by several orders of magnitude below those of the fission products even in case of underground detonations. On top of that we have the fact that--apart from the directly induced radioactivity in the nuclear weapon's construction materials--the production of radioactive nuclides due to neutron radiation in point of fact is always confined to the immediate area around ground zero.

Neutron-induced radioactivity originates due to the interaction of the fission or synthesis neutrons, released as a result of nuclear weapon detonations, with the structural elements of the weapon, the nonreacting part of the nuclear charge, as well as various elements of the surrounding medium. The character of these reciprocal processes depends heavily on the energy of the neutrons. It is above all the stable atomic nuclei which are converted into radioactive nuclides due to neutron capture.

In Section 5.2.6 we already pointed out that, in the case of nuclear fission or three-phase nuclear weapons, we get an average of one free neutron per 120 MeV of released total energy so that we get about $2.25 \cdot 10^{23}$ neutrons for a detonation intensity of 1 kt.

The reciprocal processes between these neutrons and the surrounding medium specifically depend on:

The density and the energy spectrum of the neutrons at the particular point in space and

The concentration and action cross-sections[16] if the nuclei able to be radio-activized by the elements of the surrounding medium.

Low-energy neutrons were captured with greater probability than those of higher energy. The nuclei forming due to neutron capture are in the excited state and can subsequently be subjected to beta decay which can be accompanied with the emission of gamma radiation.

For the majority of nuclei we find applicable $\sigma_1(n,\gamma) \sim E^{-1/2}$ for the action cross-section of neutron capture with subsequent radioactive decay for low-energy neutrons and we find applicable $\sigma_1(n,\gamma) \sim E^{-1}$ for high-energy neutrons.[17]

To estimate the orders of magnitude of neutron-induced radioactivity, Lavrenchik[18] starts with the assumption that high-energy neutrons are very quickly slowed down by elastic or inelastic processes of scatter (see Section 5.3.1.2) and he therefore performs the calculations on the basis of the capture of thermal neutrons in an infinite medium.

Under these assumptions, the number of developing nuclei of a certain radionuclide is directly proportional to the neutron flux F and the product from the concentration of the initial nuclei of this nuclide m_1 and their capture cross-section σ_1 and it is inversely proportional to the sum of the products from the concentrations of other nuclides m_μ and their capture cross-section σ_μ.

If we label the neutrons spent for the formation of a radionuclide with N_1, then the following applies:

$$N_1 = \frac{F \cdot m_1 \cdot \sigma_1}{\sum_{k=1}^{n} (m_\mu \cdot \sigma_\mu)_k} \qquad (7.3)$$

In addition to the processes of elastic and inelastic scatter and neutron capture with subsequent radioactive decay, however, we must expect further reciprocal processes after the use of multi-phase nuclear weapons.

For example, high-energy neutrons (superfast neutrons) with nuclei of light elements can lead to reactions of type (n, α) and (n, p).

In the structural elements used in the nuclear weapon and the unfissioned part of the nuclear charge, the reaction (n, 2n) under these conditions also plays a great role. For example, for neutrons with an energy of 14 MeV (see Section 5.1.3), the cross-section of radioactive capture averages no more than 1 percent of the cross-section of the reaction (n, 2n). Due to the

action of these neutrons, the corresponding nuclides U-232, U-234, U-235, and Pu-238 are formed from the nuclei of the nuclear charge U-233, U-235, U-238, and Pu-239. In a similar manner, the radionuclides Mn-54, Fe-53, Fe-55, W-181, and W-185 are formed in the construction elements. The significance of radioactive neutron capture then grows with the decline in the energy of the neutrons.

Because of the high neutron density, repeated capture reactions are possible in conjunction with nuclear fission and nuclear synthesis processes for the unfissioned part of the nuclear charge. For example, small quantitites of the nuclides Es-255 and Fm-255 were proved and their formation requires 17 successive capture reactions.

The radionuclides, induced by the neutron component of instantaneous nuclear radiation, other things being equal, depend on the type of detonation or, better still, on the elementary composition of the surrounding medium.

The air's induced radioactivity can essentially be traced back to the radionuclide Ar-41. The radionuclides Al-28, Mn-56, Na-24, Si-31, and Fe-59 are primarily responsible for the induced radioactivity of the ground. The induced radioactivity of sweet water is small and is based primarily on radionuclides Mn-56 and Na-24; the induced radioactivity of salt water on the other hand can be very high and is caused above all by the radionuclides Na-24, Cl-38, Br-80, and K-42.

Because the percentage share of these elements in the ground and in the other media is not constant, we get locally widely differing radioactivity conditions.

Table 7.7 shows the theoretical values of the possible activation sources for a three-phase nuclear weapon with a detonation intensity of 1 Mt ($2 \cdot 10^{26}$ free neutrons, including half of them with an energy of about 14 MeV).

Table 7.6. Characteristics of the Most Important Neutron-Induced Radionuclides in the Earth's Crust, Ocean Water, River Water, and the Air after a 20-kt Detonation ($6 \cdot 10^{24}$ Neutrons) according to Lavrenchick[19]

Parameter 1	Elemente, die einen entscheidenden Beitrag			zur summaren induzierten Aktivität leisten			
2 **Erdrinde**	Si	Fe	Ca	Na	K	P	Mn
3 Anteil/g cm^{-3}	0,74	0,13	0,10	0,075	0,07	0,003	0,002
4 Anzahl der Atome des Elements je Kubikzentimeter Boden	$1,5 \cdot 10^{22}$	$1,4 \cdot 10^{22}$	$1,5 \cdot 10^{21}$	$2 \cdot 10^{21}$	$1,1 \cdot 10^{21}$	$6 \cdot 10^{19}$	$2,2 \cdot 10^{19}$
5 induziertes Radionuklid	Si-31	Fe-59	Ca-45	Na-24	K-42	P-32	Mn-56
6 Einfangquerschnitt für thermische Neutronen/barn	0,4	2,5	0,63	0,51	1,2	0,19	13
7 Anzahl der aktivierten Kerne: $F \cdot m_i \cdot \sigma_i / \Sigma m_\mu \cdot \sigma_\mu$	$3,6 \cdot 10^{21}$	$3 \cdot 10^{20}$	$4 \cdot 10^{20}$	$2 \cdot 10^{22}$	$5,5 \cdot 10^{20}$	$2,2 \cdot 10^{20}$	$5,8 \cdot 10^{21}$
8 Aktivität 1 h nach der Detonation/Ci	$5,2 \cdot 10^{6}$	$1,3 \cdot 10^{3}$	540	$6,8 \cdot 10^{6}$	$1,4 \cdot 10^{5}$	$3,4 \cdot 10^{3}$	$1,4 \cdot 10^{7}$
9 Aktivität 1 d nach der Detonation/Ci	$1,4 \cdot 10^{4}$	$1,3 \cdot 10^{3}$	538	$2,2 \cdot 10^{6}$	$3,8 \cdot 10^{4}$	$3,2 \cdot 10^{3}$	$2,4 \cdot 10^{4}$
10 **Meerwasser**	Na	Cl	S	Mg	Ca	K	Br
11 Konzentration/g cm^{-3} $H_2O \cdot 10^{-3}$	10,5	19,2	0,9	1,3	0,4	0,4	0,3
12 Anzahl der Atome des Elements je Kubikzentimeter Wasser	$2,7 \cdot 10^{20}$	$3,3 \cdot 10^{20}$	$1,7 \cdot 10^{19}$	$3 \cdot 10^{19}$	$6 \cdot 10^{18}$	$6 \cdot 10^{18}$	$2,3 \cdot 10^{18}$
5 induziertes Radionuklid	Na-24	Cl-38	S-35	Mg-27	Ca-45	K-42	Br-80
6 Einfangquerschnitt für thermische Neutronen/barn	0,5	0,56	0,26	0,06	0,63	1,2	10,4
7 Anzahl der aktivierten Kerne: $F \cdot m_i \cdot \sigma_i / m \cdot \sigma^1$)	$3,7 \cdot 10^{22}$	$1,2 \cdot 10^{22}$	$4,7 \cdot 10^{19}$	$5,4 \cdot 10^{19}$	$2 \cdot 10^{19}$	$1,3 \cdot 10^{20}$	$3,8 \cdot 10^{21}$
8 Aktivität 1 h nach der Detonation/Ci	$1,2 \cdot 10^{7}$	$2,5 \cdot 10^{7}$	$1,1 \cdot 10^{2}$	$1,7 \cdot 10^{4}$	27	$5,3 \cdot 10^{4}$	$3,5 \cdot 10^{6}$
9 Aktivität 1 d nach der Detonation/Ci	$4 \cdot 10^{6}$	–	$1,1 \cdot 10^{2}$	–	27	$1,3 \cdot 10^{4}$	10^{3}

[Continued on following page]

Table 7.6. [Continued from preceding page]

	Parameter 1	Elemente, die einen entscheidenden Beitrag zur summaren induzierten Aktivität leisten		
13	Flußwasser	Cu	Mn	Na
11	Konzentration/g cm^{-3} $H_2O \cdot 10^{-6}$	0,02	0,3	6,0
12	Anzahl der Atome des Elements je Kubikzentimeter Wasser	$1,9 \cdot 10^{14}$	$3,3 \cdot 10^{15}$	$1,6 \cdot 10^{17}$
5	induziertes Radionuklid	Cu-64	Mn-56	Na-24
6	Einfangquerschnitt für thermische Neutronen/barn	4,3	13	0,5
7	Anzahl der aktivierten Kerne: $F \cdot m_i \cdot \sigma_i/m \cdot \sigma^1)$	$2,2 \cdot 10^{17}$	$1,2 \cdot 10^{19}$	$2,1 \cdot 10^{19}$
8	Aktivität 1 h nach der Detonation/Ci	120	$2,5 \cdot 10^{4}$	10^{4}
9	Aktivität 1 d nach der Detonation/Ci	37	160	3500
14	Luft	N	Ar	
15	Anzahl der Atome des Elements je Kubikzentimeter Luft	$4,3 \cdot 10^{19}$	$5,6 \cdot 10^{17}$	
5	induziertes Radionuklid	C-14	Ar-41	
6	Einfangquerschnitt für thermische Neutronen/barn	1,75	0,53	
7	Anzahl der aktivierten Kerne: $F \cdot m_i \cdot \sigma_i/\Sigma m_\mu \cdot \sigma_\mu$	$5,7 \cdot 10^{24}$	$2,4 \cdot 10^{22}$	
8	Aktivität 1 h nach der Detonation/Ci	620	$4 \cdot 10^{7}$	
9	Aktivität 1 d nach der Detonation/Ci	620	$4 \cdot 10^{3}$	

Key: 1--Elements making a decisive contribution to summary [cumulative] induced radioactivity; 2--Earth's crust; 3--Share, g/cm^{-3}; 4--Number of atoms of the element per cm^3 of ground; 5--Induced radionuclide; 6--Capture cross-section for thermal neutrons, barn; 7--Number of activated nuclei; 8--Radioactivity 1 hour after detonation, Ci; 9--Radioactivity 1 day after detonation, CI; 10--Ocean water; 11--Concentration; 12--Number of atoms of element per cm^3 water; 13--River water; 14--Air; 15--Number of atoms of element per cm^3 of air. (1) In these figures, m is the number of hydrogen nuclei per cm^3 and σ is the capture cross-section of hydrogen for thermal neutrons.

Table 7.7. Ratio between the Various Activation Sources after Detonation of 1-Mt Nuclear Weapon

1 Quelle der Aktivierung	2 Aktivität/Ci nach 1 Tag 3	7 Tagen 4	50 Tagen 5
Spaltprodukte 6			
($7,2 \cdot 10^{25}$ Spaltprozesse) 7	$4 \cdot 10^{9}$	$4 \cdot 10^{8}$	$4 \cdot 10^{7}$
U-237 aus der Reaktion (n, 2n) 8			
mit U-238 (10^{25} Neutronen)	$2 \cdot 10^{8}$	$1 \cdot 10^{8}$	$6 \cdot 10^{5}$
induzierte Nuklide: 9			
in der Erdrinde 10	10^{8}	$1,4 \cdot 10^{6}$	10^{6}
im Süßwasser 11	10^{5}	$5 \cdot 10^{2}$	10^{2}
im Meerwasser 12	10^{7}	$4 \cdot 10^{5}$	$2 \cdot 10^{5}$
in der Luft 13	10^{5}	$2 \cdot 10^{4}$	$2 \cdot 10^{4}$

Key: 1--Source of radioactive contamination; 2--Radioactivity, Ci; 3--1 day; 4--7 days; 5--50 days; 6--Fission products; 7--Fission processes; 8--U-237 from the reaction (n, 2n) with U-239 (10^{25} neutrons); 9--Induced nuclides; 10--In earth's crust; 11--In sweet water; 12--In ocean water; 13--In air.

The calculations were made on the basis of an infinite medium and using the capture cross-section for thermal neutrons. The table shows that the essential share out of the total radioactivity comes from the fission products.[20]

To investigate radioactive contamination of the terrain under field conditions we are above all interested in the induced radioactivity of the ground in the area of ground zero after air bursts. Here, the total radioactivity as a rule is traced back to the radionuclides Al-28, Mn-56, and Na-24, while the other shares (see Table 7.6) are neglected.

During the first few minutes after the detonation, the radionuclide Al-28 ($T_{1/2}$ = 2.3 min) contributes decisively to the cumulative dose rate of gamma radiation with 1.8 MeV per decay, whereas during the period of time of up to 1 week, the radionuclides Mn-56 (1.2 MeV/decay) and Na-24 (4.2 Mev/decay) supply the main shares. After that, the radionuclide Fe-59 (1.2 MeV/decay) assumes significance.

To be able to make specific statements as to the physical behavior of induced nuclides, it is necessary to start with a certain soil composition. Table 7.8 provides some reference values for this.

Table 7.8. Some Data on the Radionuclides Primarily Responsible for the Induced Radioactivity of the Ground[21]

Parameter	Element Al	Na	Mn
durchschnittliche Verbreitung/% 1			
in der Erdrinde 2	7,85	2,8	0,075
im Podsolboden 3	3,9	0,67	0,02
in kastanienfarbener Erde 4	6,7	0,9	0,28
in Schwarzerde 5	6,9	0,7	0,02
in Grauerde 6	6,8	1,7	–
Berechnungswert 7	7	1	0,06
Einfangquerschnitt für thermische Neutronen/barn 8	0,215	0,51	13
induziertes Radionuklid 9	Al-28	Na-24	Mn-56
Halbwertzeit 10	2,3 min	14,9 h	2,6 h

Key: 1--Average spread, %; 2--In the Earth's crust; 3--in Podsol ground; 4--In chestnut-colored earth; 5--In black earth; 6--In grey earth; 7--Calculation value; 8--Capture cross-section for thermal neutrons, barn; 9--Induced radionuclides; 10--Half-life.

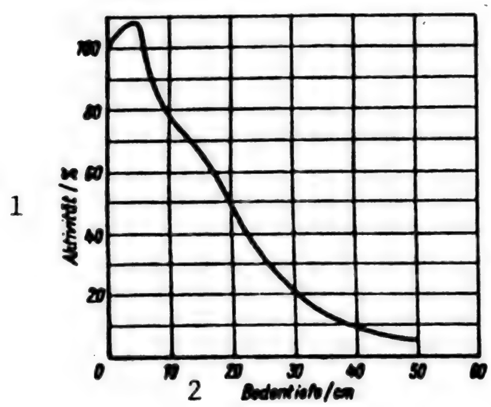


Figure 7.8. Approximate percentage distribution of induced radioactivity as function of soil depth for low-altitude air bursts of nuclear fission weapons. Key: 1--Radioactivity, %; 2--Soil depth, cm.

The calculation of neutron-induced radioactivity in the detonation area of air bursts on the basis of the radionuclides Al-28, Mn-56, and Na-24 (using the calculation values given in Table 7.8 for the shares of the individual elements in mass-percent [weight-percent]) gives an average error of 30 percent for the equation[22]

$$\sum A_i(t) = F(1{,}87 \cdot 10^{-4} \cdot e^{-18t} + 7{,}15 \cdot 10^{-7} \cdot e^{-0{,}269t} + 2{,}06 \cdot 10^{-7} \cdot e^{-0{,}046t}) \quad Z\,\mathrm{min}^{-1}\,\mathrm{cm}^{-3} \qquad (7.4)$$

From this it finally follows for the defined conditions that:

$$P(t) = P_0 \frac{810 \cdot e^{-18t} + 1{,}97 \cdot e^{-0{,}269t} + 2{,}08 \cdot e^{-0{,}046t}}{810 \cdot e^{-18t_0} + 1{,}97 \cdot e^{-0{,}269t_0} + 2{,}08 \cdot e^{-0{,}046t_0}} \quad \mathrm{R\,h}^{-1} \qquad (7.5)$$

F--flux of slow (thermal) neutrons, n cm^{-2}; t--time after detonation, hrs;
P--dose rate of gamma radiation, R hr^{-1}.

While the radioactive fission products from a nuclear weapon detonation are deposited on the earth's surface, the induced radionuclides are formed up to a certain soil depth. For low-level air bursts involving nuclear fission weapons, the percentage radioactivity distribution as a function of the soil depth is illustrated in Figure 7.8.

We can see that a part of the neutrons must be slowed down to thermal speeds only in the upper soil layer to be captured. From this we can conclude that the radioactivity maximum will be shifted to an even greater soil depth following the detonation of three-phased nuclear weapons and nuclear synthesis weapons.

The graphic illustration furthermore shows that almost 50 percent of the induced nuclides are formed at a soil depth of more than 20 cm and that about 10 percent are formed below 40 cm. Under these conditions, in other words, radioactive decontamination by removing the upper soil layer would not be successful.

In case of ground and underground detonations (we cannot go into any greater detail here regarding water and underwater detonations), there is a more or less close mixing of the fission products and the induced nuclides. Estimates concerning the radioactivity performance of both components beyond the values given in Tables 7.6 and 7.7 are difficult and there are very few indications in the accessible literature on that score.

One must first of all keep in mind here that it is impossible to base such calculations simply on the given "average" soil composition. For example, the data published as part of the American Plowshare Program[23] concerning radioactive contamination are based on a soil share of 14.5 percent aluminum, 0.18 percent manganese, and 4.9 percent sodium. These values are considerably higher than those assumed for formulas 7.4 and 7.5. In addition we have the fact that the detonation depth and thus also the mechanism of crater ejection has a strong effect on the properties and the distribution pattern of summary [cumulative] radioactive detonation products.

A basic illustration of this problem complex can be found among others in Nifontov.[24]

Accordingly one may assume that, in case of detonations with a complete internal effect, all neutrons are already essentially absorbed by the rocks within a radius of 1 m; that is to say, they are slowed down to thermal speeds and they are then captured. This undoubtedly even in smaller detonation depths leads to a situation where the induced radionuclides and the fission products are closely mixed and are ejected with the evaporated or melted earth.

Because of the low climbing altitude of the detonation cloud after underground detonations, compared to air detonations, and because of the deposit of a

large part of the radioactive detonation products directly in the area of the crater or in its vicinity, in the direction in which the detonation cloud moves off, the radioactivity of the fission products here likewise predominates in spite of the absolutely higher values of induced radioactivity.

In the area of the crater, just one day after detonation, the induced radioactivity came to 20-25 percent of the radioactivity of the fission products and then dropped to 1 percent in the course of a week.

Summarizing we can say that it is permissible with a great degree of probability to use the $t^{-1.2}$ law of fission products in rough calculations of the decline in dose rates after underground detonations. But a critical interpretation of the measurement or computation results is necessary here. This applies particularly to forward-looking dose calculations. One must furthermore keep in mind that the influence of induced radioactivity can be reflected not only in the immediate detonation area but in the entire fallout region. This is why several successive control measurements are necessary. This problem complex will be covered in greater detail in Section 7.4.

The radionuclides induced by the neutron component of instantaneous nuclear radiation in the soil, in the water, and in the air, are beta-active and beta-gamma-active. Concerning the soil's induced radioactivity, we can say that the average maximum energy of the beta particles and the average energy of the gamma quantums in the time interval of interest here, after the detonation (up to a maximum of one week), will be above the corresponding values of the fission products.

The nuclear radiation emitted by the induced radionuclides therefore during the first 4 days after the detonation will not only fade more slowly than that of the fission products but it also has a considerably greater penetration capacity than the former.

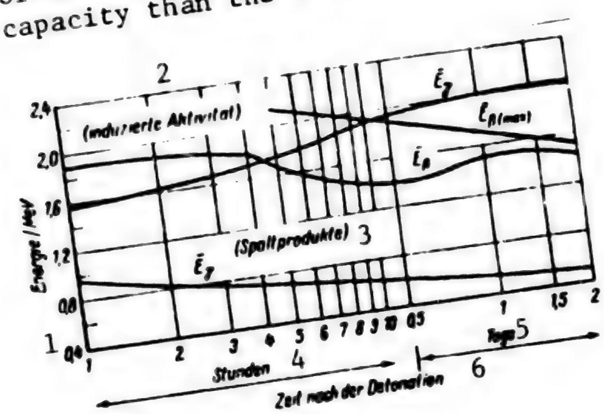


Figure 7.9. Change in energy of nuclear radiation, emitted by induced radionuclides in the ground, as a function of the time after the nuclear weapon detonation. Key: 1--Energy, MeV; 2--Induced radioactivity; 3--Fission products; 4--Hours; 5--Days; 6--Time after detonation.

Figure 7.9 illustrates some approximation values on the change of the average energy of gamma radiation and the average and average maximum energy of beta radiation of radionuclides induced in the soil over a period of time after nuclear weapon detonation.

Due to the effect of neutron radiation from a nuclear weapon detonation, we can also have the formation of induced radionuclides in various materials in combat equipment, ration items, etc. Generally valid statements on this **problem complex** are impossible and computations are rather complicated and time-consuming in detail. Besides, the accuracy attainable with simple aids leaves much to be desired. Nevertheless, such rough calculations may become necessary under certain conditions. The following formula can be used for this purpose.[25]

$$\Sigma A_i(t) = 0{,}017 \cdot F \sum_{i}^{n} 6 \cdot 10^{19} \cdot \rho_i \cdot a_i \cdot b_i \cdot \frac{1}{M_i} \cdot \sigma_i \cdot \lambda_i \cdot e^{-\lambda \cdot t} \qquad (7.6)$$

$\Sigma A_i(t)$ --Specific induced summary [cumulative] beta activity at time t after detonation, Z min^{-1} cm^{-3}

F--Flux of slow (thermal) neutrons, n cm^{-2}

ρ_1--Density of i-th element, g cm^{-3}

σ_1--Share of i-th element in the substance to be investigated, mass-percent

b_1--share of radioactive isotope of the i-th element, %; if the element contains several essentially radioactive isotopes, the expression under the sum symbol for the i-th element must be separately calculated for each isotope and must be inserted as a partial sum into the total sum

M_i--Atomic mass of the i-th element, relative units

σ_i--Capture cross-section of considered isotope of i-the element, cm^{-3}

λ_1--Decay constant of considered radionuclide of i-the element, hr^{-1}

t--Time after detonation, hrs

n--Number of general elements designated with i which are to be included in the investigation.

In concluding the elementary considerations of neutron-induced radioactivity, Table 7.9 summarizes some characteristic data on important induced radionuclides.[26]

7.9. Characteristic Data on Important Induced Radionuclides Derived from Nuclear Weapon Detonation

	Radionuklid 2	Symbol 3	Strahlungstyp 4	Halbwertzeit	$E_{\beta(max)}$ / MeV	$E_{\beta(mittel)}$ / MeV
1						
10	Kohlenstoff-14	$^{14}_{6}C$	β^-	5568 a	0,16	0,05
11	Natrium-24	$^{24}_{11}Na$	β^-, γ	14,9 h	1,4	0,54
	Magnesium-27	$^{27}_{12}Mg$	β^-, γ	9,45 min	1,7	1,68
12	Silizium-31	$^{31}_{14}Si$	β^-, γ	2,6 h	1,47	—
13	Phosphor-32	$^{32}_{15}P$	β^-	14,5 d	1,7	0,69
14	Schwefel-35	$^{35}_{16}S$	β^-	87,1 d	0,17	0,06
15	Chlor-38	$^{38}_{17}Cl$	β^-, γ	37,7 min	4,8	1,39
	Argon-41	$^{41}_{18}Ar$	β^-, γ	1,8 h	1,2	0,4
16	Kalium-42	$^{42}_{19}K$	β^-, γ	12,5 h	3,6	1,4
	Calcium-45	$^{45}_{20}Ca$	β^-	153 d	0,26	0,08
17	Mangan-56	$^{56}_{25}Mn$	β^-, γ	2,6 h	2,86	0,89
18	Eisen-59	$^{59}_{26}Fe$	β^-, γ	45 d	1,56	0,12
19	Kupfer-64	$^{64}_{29}Cu$	β^-, β^+, γ	12,8 h	0,57 β^- 0,66 β^+	0,13

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Table 7.9. [Continued from preceding page]

E_{γ} / MeV	5 Anteil der Gammaquanten je Zerfallsprozeß/%	6 Angaben zum Verhalten bei Inkorporation: kritische Organe 7	8 biologische Halbwertzeit	9 effektive Halbwertzeit
–	–	20 Fett	12 d	12 d
		21 Knochen	40 d	40 d
2,75	100	22 Gesamtkörper	11 d	0,6 d
1,37	100			
1,02	30,1			
0,33	70	–	–	–
0,18	0,63			
1,26	0,07	–	–	–
–	–	21 Knochen	3,2 a	14,1 d
		23 Leber	18 d	8 d
		22 Gesamtkörper	257 d	13,5 d
–	–	21 Knochen	1,7 a	76 d
		22 Gesamtkörper	1,2 a	90 d
2,16	47	–	–	–
1,60	31			
1,29	99	–	–	–
1,51	18,2	Muskeln	58 d	0,5 d
0,32	0,2	22 Gesamtkörper	58 d	0,5 d
–	–	21 Knochen	49,4 a	152 d
		22 Gesamtkörper	45 a	152 d
2,9	0,2	23 Leber	25 d	0,1 d
2,6	0,1	24 Nieren	6,8 d	0,1 d
2,1	14,8	22 Gesamtkörper	17 d	0,11 d
1,8	24,9			
0,84	99,7			
1,29	43	23 Leber	1,5 a	41,7 d
1,10	56,7	21 Knochen	4,4 a	44 d
0,19	2,8	22 Gesamtkörper	2,2 a	43 d
1,34	0,43	22 Gesamtkörper	80 d	0,5 d
0,51	38			

Key: 1--Radionuclides; 2--Radiation type; 3--Half-life; 4--Average; 5--Share of gamma quantums per decay process, %; 6--Data for response in case of incorporation; 7--Critical organs; 8--Biological half-life; 9--Effective half-life; 10--Carbon-14; 11--Sodium-24; 12--Silicon-31; 13--Phosphorus-32; 14--Sulfur-35; 15--Chlorine-38; 16--Potassium-42; 17--Manganese-56; 18--Iron-59; 19--Copper-64; 20--Fat; 21--Bones; 22-Whole body; 23--Liver; 24--Kidneys.

Table 7.10. Characteristic Data on the Most Important Nuclear Fission Substances in Nuclear Weapons

Radionuklid 1	Symbol	Strahlungstyp 2	Halbwertzeit/a 3	Energie der Alphateilchen E_α/MeV und (Anteil/%) 4	$\frac{E_{\alpha\,(mittel)}}{MeV}$ 5	Energie der Gammaquanten E_γ/MeV und (Anteil je Zerfallsprozeß/%) 6
Thorium-232	$^{232}_{90}Th$	α, γ	$1{,}4 \cdot 10^{10}$	3,93 (24); 3,99 (76)	3,98	0,059 (24)
13 Uran-233	$^{233}_{92}U$	α, γ	$1{,}6 \cdot 10^{5}$	4,82 (83,5); 4,77 (14,9) 4,72 (1,6); 4,66 (0,07) 4,58 (0,04); 4,49 (0,03)	4,8	0,056 (0,01) 0,043 (0,05)
14 Uran-235	$^{235}_{92}U$	α, γ	$7{,}1 \cdot 10^{8}$	4,58 (10); 4,47 (3) 4,40 (83); 4,20 (4)	4,4	0,382 (2); 0,289 (6) 0,184 (40); 0,110 (43) 0,074 (40)
15 Uran-238	$^{238}_{92}U$	α, γ	$4{,}5 \cdot 10^{9}$	4,18 (77); 4,14 (23) 4,02 (0,1)	4,1	0,112 (0,1) 0,048 (23,1)
Plutonium-239	$^{239}_{94}Pu$	α, γ	$2{,}4 \cdot 10^{4}$	5,15 (69); 5,14 (20) 5,10 (11)	5,1	0,051 (5,5) 0,038 (5,5)

Radionuklid	$\frac{E_{\gamma\,(mittel)}}{MeV}$	Dosiskonstante k_γ $\frac{}{R\,m^{-2}\,h^{-1}\,Ci^{-1}}$ 7	Spezifische Aktivität C/Ci kg^{-1} 8	9 Angaben zum Verhalten bei Inkorporation: kritische Organe 10	biologische Halbwertzeit 11	effektive Halbwertzeit 12
Thorium-232	0,06	0,0068	$1{,}1 \cdot 10^{-4}$	16 Knochen 17 Gesamtkörper	200 a 150 a	200 a 150 a
Uran-233	0,04	$2{,}6 \cdot 10^{-3}$	9,5	17 Gesamtkörper	200 d	200 d
Uran-235	0,13	0,09	$2{,}1 \cdot 10^{-3}$	16 Knochen 17 Gesamtkörper	300 d 200 d	300 d 200 d
Uran-238	0,05	0,009	$3{,}3 \cdot 10^{-4}$	16 Knochen 17 Gesamtkörper	300 d 200 d	300 d 200 d
Plutonium-239	0,04	0,005	60	16 Knochen 17 Gesamtkörper	200 a 178 a	197 a 175 a

Key: 1--Radionuclide; 2--Radiation type; 3--Half-life, a; 4--Energy of alpha particles E_α MeV, and (share, %); 5--Average; 6--Energy of gamma quantums E_γ, MeV and (share per decay process, %); 7--Dose constant; 8--Specific radioactivity; 9--Date for response of in case of incorporation; 10--Critical organs; 11--Biological half-life; 12--Effective half-life; 13--Uranium-233; 14--Uranium-235; 15--Uranium-238; 16--Bones; 17--Whole body.

7.1.3. Unfissioned part of Nuclear Charge

In addition to the fission products and the neutron-induced radioactivity, radioactive detonation products also include the part of the nuclear charge which is not involved in the reaction. The share of this source of residual nuclear radiation out of the total radioactivity generated during nuclear weapon detonations is not constant but changes as a function of the type of nuclear weapon, the types of energy released, and their contribution to the summary [cumulative] detonation energy, as well as especially the particular nuclear fission efficiency.

In the case of the unfissioned part of the nuclear charge of nuclear fission weapons and three-phase nuclear weapons, we are exclusively dealing with alpha-active radionuclides with long half-life and low specific radioactivities. Although alpha radiation has a great biological effect, the unfissioned part of the nuclear charge therefore as a rule only plays a subordinate role as a source of residual nuclear radiation.

As we can see in Table 7.10, only Pu-239--which is mostly used as nuclear charge for nuclear fission weapons--has a noteworthy specific activity. But here again this kind of radioactivity amount does not turn out to be significant if we start with nuclear weapons in which we want maximum nuclear fission efficiency. The situation is somewhat different in the case of the so-called subcaliber nuclear weapons (Section 1.3.3). Here the alpha radioactivity can be significant with a view of increased danger of incorporation especially after ground and underground detonations in the area around ground zero or the detonation crater and its immediate vicinity. This means basically that measurements and considerations concerning alpha radioactivity are of primary importance wherever there is an objective danger of incorporation of radioactive substances, in other words, in the sector of ration supply, water supply, etc. The need for wearing a mask may arise furthermore also even at comparatively low dose rates. These problems will be covered in greater detail later on.

The gamma radiation accompanying alpha decay process is small in terms of the share and the energy involved and therefore does not make any essential contribution to the cumulative dose rate of the detonation products. This is expressed among other things in the dose constants given in Table 7.10.

In conclusion we might mention that, in the case of three-phase nuclear weapons with a casing of U-238, Pu-239 can also be formed due to neutron capture.

$$^{238}_{92}U + 1n \rightarrow {}^{239}_{92}U \xrightarrow[24\ min]{\beta} {}^{239}_{93}Np \xrightarrow[2.3\ d]{\beta} {}^{239}_{94}Pu$$

But because the action cross-section for this capture reaction is small, one may estimate that the plutonium quantity produced in this way is small.

7.1.4. General Properties of Alpha, Beta, and Gamma Radiation

As we were able to see clearly in sections 7.1 to 7.3, the residual nuclear radiation, emitted by radioactive detonation products, can consist of three components: alpha, beta, and gamma radiation.

Unit operations in radioactively contaminated areas lead to a potential danger of radiation damage, specifically, both due to external radiation and also due to direct incorporation of radioactive substances.

In this connection one must keep in mind that the three developing types of nuclear radiation by virtue of their different physical properties also cause different biological effects. We are particularly interested here in the specific penetration and ionization capacity of the individual nuclear radiation types because their relative degree of danger can be derived from that. In case of external radiation, concerning the threat to man, we get the general sequence of gamma, beta, and alpha radiation; in case of the incorporation of radioactive substances however one must use the exact opposite sequence as basis. This leads us to a series of necessary and possible measures for nuclear radiation protection for units under field conditions; to develop a full understanding of these measures it is necessary here to present some elementary statements on the individual types of nuclear radiation.

7.1.4.1. Alpha Radiation

The alpha radiation (α-radiation) emitted by the unfissioned part of the nuclear charge is a corpuscular radiation. The structure of the alpha particles corresponds to that of the atomic nuclei of the chemical element Helium (${}^4_2H^{++}$). Each alpha particle consists of two protons and two neutrons which are bound to each other with a binding energy of about 7 MeV per nucleon.

Upon each alpha decay, the mass number of the initial nuclide is accordingly diminished by 4 units and the nuclear charge number is diminished by 2 units. That gives us the daughter nuclide in the Periodic System of Elements in each case two digits to the left of the initial nuclide.

In general, the following applies:

$${}^A_ZX \rightarrow {}^{A-4}_{Z-2}Y + \alpha$$

Or the following applies for the decay of Pu-239:

$${}^{239}_{94}Pu \rightarrow {}^{235}_{92}U + \alpha$$

The energy spectrum of alpha radiation of a certain radionuclide is discrete; that is to say, all emitted alpha particles either have the same energy or they can be combined into groups of monoenergetic particles. In the first case, the decay as a rule leads to the basic state of the daughter nucleus while in case of appearance of several "alpha lines" we can get excited states which then fade out along with the emission of gamma quantums.

It is generally customary to illustrate the alpha decay in a term diagram. Here, the energy levels of the atomic nuclei of the initial element and the daughter element and likewise the recognizable intermediate states are characterized by horizontal lines between which the interval is proportional to the energy of these levels.

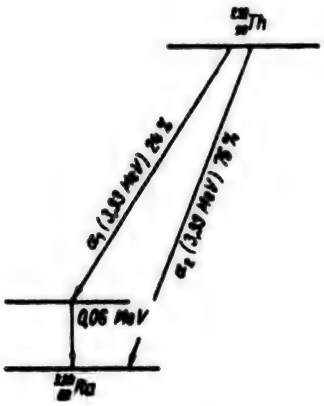


Figure 7.10. Simplified term diagram for Th-232

The energy of the alpha particles, emitted by the unfissioned part of the nuclear charge, is 4-5 MeV. Upon passage through a substance, the alpha particles give off this energy almost exclusively, due to the electrostatic reciprocal effect, to the electrons in the atomic envelope; that is to say, they use them up for ionization. The energy, transmitted on the average to an electron via all substances, is small and amounts to 100-200 eV. In the specific case, the ionizing work to be expended for the formation of an ion pair depends on the type of the irradiated substance.

For air, for example, it only has a value of 32.5 eV (including other marginal processes, it would be 35 eV). This is equivalent to the generation of about 150,000 ion pairs.

The energy of the alpha particles is usually characterized by their range (path, distance) in air (at 15° C and 760 mm Hg). According to the law of Geiger, the range $\bar{R}_{\alpha(L)}$ of the alpha particles is connected with their initial velocity v_0 by the following relationship:

$$R_{\alpha(L)} = k \cdot v_0^3 \quad \text{cm} \qquad (7.7)$$

Here, k has the value $9.25 \cdot 10^{-28}$ s^3 cm^{-2}. (An initial velocity of $1.5 \cdot 10^9$ cm s^{-1} roughly corresponds to the energy of an alpha particle of 5 Mev.)

The range of alpha particles of equal energy decreases as the density of an absorber increases. It can be determined for substances of differing density from the range in the air with the help of the Bragg-Kelmann rule (accuracy $\pm 15\%$):

$$R_\alpha = 3 \cdot 10^{-4} \frac{R_{\alpha(L)}}{\rho} A^{1/2} \quad \text{cm} \qquad (7.8)$$

R_α--Range of alpha particle in particular substance, cm
$R_{\alpha(L)}$--Range of same particle in air, cm
ρ--Density of substance, g cm^{-3}
A--Mass number of substance, Me.

Table 7.11. Range R_α of Alpha Particles in Air, in Biological Tissue, and in Aluminum as a Function of their Energy[27]

$\frac{E_\alpha}{MeV}$	1 in Luft cm	2 in biologischem Gewebe µm	R_α 3 in Aluminium µm
4	2,5	31	16
4,5	3,0	37	20
5	3,5	43	23
5,5	4,0	49	26

Key: 1--In air; 2--In biological tissue; 3--Aluminum.

Another possibility for describing the penetration capacity of alpha radiation consists in expressing its range by the surface dimensions of an absorber. (For air, in the energy range of alpha particles of interest here, it is 4 mg cm^{-3}.) This offers the advantage that, in such calculations, we do not need any data as to the density or state of the absorber.

The number of ion pairs, which an alpha particle will form per millimeter of distance in air of 15° C and 760 mm Hg, is called the specific ionization. It averages around 3,000 ion pairs per mm and at the start of the trajectory it is 2,000 ion pairs per mm. This means that the specific ionization goes up toward the end of the range and that it runs through a pronounced maximum just a few millimeters away from the end of the trajectory. After that it decreases again and the alpha particle is converted into a helium atom along with the capture of two electrons.

From what we have said so far, in conjunction with Section 7.1.3, we can draw the following basic conclusions.

Alpha radiation as a component of residual nuclear radiation has a great ionization capability but only a very low penetration capacity. The range of alpha particles in air does not exceed several centimeters and in liquid or solid substances it does not exceed several hundredths of a millimeter. This is why alpha radiation under field conditions is of practically no significance as an outside radiation source. But it is very dangerous in case of incorporation of alpha-active substances and in its immediate action area it is up to tens of times more effective than gamma radiation in biological respects.

We cannot go into any great detail here in covering the measurement technique problems connected with alpha radiation. Reference is made here among other things to the book entitled "Kernwaffenradiometrie und Kernwaffendetonometrie" by Langhans.[28]

Some special questions on the biological effect will be covered in greater detail in Section 7.4.

7.1.4.2. Beta Radiation

By far the greatest part of the radioactive detonation products--fission products and radionuclides induced by neutron radiation--are beta-active. Beta radiation (β-radiation), like alpha radiation, is a corpuscular radiation. Depending upon the type of beta decay, simple-negative-charged or simple-positive-charged particles are radiated with the mass of an electron.

Specifically we therefore distinguish between the negatron decay and the positron decay. Another type of beta conversion is K capture. The two last-named processes however play a completely subordinate role in the context to be examined here and will therefore not be considered in any greater detail.

Negatron-beta decay appears in those radionuclides which reveal a neutron surplus. In the process of this kind of beta decay, a neutron is converted into a proton and a beta particle, with a mass and elementary charge equivalent to an envelope electron, is emitted.

The radiated beta particles, compared to the neutrons and protons forming the atomic nucleus, have only a very small mass; this is why the total mass of the atomic nuclei changes only very little after a beta decay, that is to say, the mass number remains the same.

In general, negatron decay can be illustrated as follows:

$$\bullet + {}_{-}\beta + {}^{1+Z}_{V} \leftarrow X^{Z}_{V}$$

or we have the following for the decay of the radionuclide Sr-90:

$${}^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + \beta^{-} + \nu$$

In this way, if we have a β^- decay, we each time get the nuclide of a new chemical element which, in the Periodic System, can be found one digit to the right of the initial element.

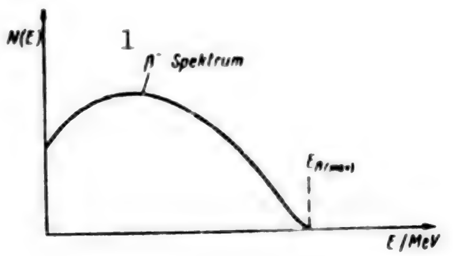


Figure 7.11. Typical shape of β^- spectrum. Key: 1--β^- spectrum.

In contrast to alpha radiation, the beta radiation of a radionuclide reveals a continuing energy spectrum. This can be explained by saying that, upon each beta decay, in addition to the radiated beta particles, an additional particle--a so-called neutrino (ν)--is released. Because of that, the energy released upon the beta decay of a radionuclide is distributed over the beta particle and the neutrino. The proportional energy varies. On the other

hand, the sum of the energy of the beta particle and the neutrino will always be the same for a certain radionuclide, that is to say, it will be characteristic and it corresponds to a certain maximum energy (see tables 7.3 and 7.9).

Individual beta particles have no kinetic energy whatsoever, that is to say, their initial velocity in fact is zero while others come up to 99 percent of the speed of light. The distribution maximum of beta particles generally is between 0.3 E_{max} and 0.5 E_{max}.

A part of the conversion energy is released in the form of gamma radiation also in conjunction with beta decay. While, for example, the radionuclide C-14 is a pure beta emitter, Co-60 is beta-gamma-active.

The average maximum energy of the beta particles of the fission products and of the induced radionuclides changes greatly with the time after detonation and during the first 10 days is to be found in intervals of 2.5 MeV to 0.9 MeV. Although these energy values are considerably below those of alpha radiation, beta radiation nevertheless does have a greater range.

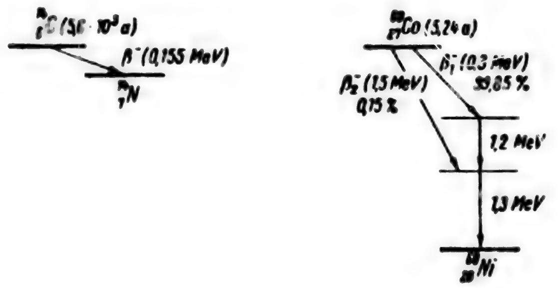


Figure 7.12. Term diagrams for C-14 and Co-60.

The attenuation of beta radiation in a substance takes place almost exclusively due to electrostatic interaction or "collisions" with the envelope electrons. Regarding the effort to be expended for the formation of an ion pair, we get the same conditions as for alpha radiation. But because the ratio between the mass of beta particles and the mass of alpha particles is roughly 1:7,300, the beta particles are strongly deflected from the original propagation direction in conjunction with their interaction with the electrons in the atomic envelopes and do not describe a straight-line movement, like the alpha particles. Because of their considerably faster speed, the specific ionization of beta radiation, at the same energy as that of the alpha particles, however is smaller. It is only on the order of magnitude of 5-10 ion pairs per millimeter of distance in the air. Although beta radiation consumes most of its energy due to a large number of ionization processes, the energy loss due to braking and scattering of beta particles, due to the effect of electrical fields of the atomic nuclei, must not be disregarded. In this interaction between negatively-charged beta particles and the positively-charged atomic nuclei, we get x-rays as "braking radiation." This energy loss can come close to the part of the energy of beta radiation, which is consumed by ionization processes, in substances with a high mass number.

From the fact that beta radiation reveals a continuing energy spectrum it follows that the range of the individual beta particles of one and the same beta-active radionuclide will differ. This is why the intensity of beta radiation upon passage through an absorber declines gradually and within certain limits follows an exponential attenuation law.

To estimate the maximum range of beta radiation of a given energy, we can use the approximation formulas developed by Feather. The following applies accordingly:

$$R_{\beta(max)} \approx \frac{0{,}407 E_{\beta(max)}^{1.38}}{\varrho} \quad \text{cm} \tag{7.9}$$

and for $E_{\beta(max)} > 0{,}8$ MeV

$$R_{\beta(max)} \approx \frac{0{,}542\, E_{\beta(max)} - 0{,}133}{\varrho} \quad \text{cm} \tag{7.10}$$

$R_{\beta(max)}$--Maximum range of beta particles, cm
$E_{\beta(max)}$--Maximum energy of beta particles, MeV
ρ--Density of absorber, g cm^{-3}

Another possibility of describing the range or penetration capacity of beta radiation, as in the case of alpha radiation, consists in the introduction of the surface dimensions [surface mass]. But here, in determining the "practical range" we start with that surface mass [dimension] through which only 1 percent of the beta particles will pass. Two empirical formulas have been established in this connection. The approximation formula according to Flammersfeld applies in the area of a maximum beta radiation energy of 0-3 MeV.

$$R_{\beta(max)} = 0{,}11 \left(\sqrt{1 + 22{,}4\, E_{\beta(max)}^2} - 1\right) \quad \text{g cm}^{-3}$$

The approximation formula according to Bleuer and Zuenti applies when $E_{\beta(max)} > 1$ MeV.

$$R_{\beta(max)} = 0{,}571\, E_{\beta(max)} - 0{,}161 \quad \text{g cm}^{-3} \tag{7.12}$$

The energy must be inserted in terms of MeV in both numerical equations.

When we use formulas 7.9-7.12, we must keep in mind that considerable errors are possible due to the self-absorption of low-energy beta particles in the detonation product mixture or due to the back-scatter from a support.

One must for example expect that, if we have a steel surface contaminated by radioactive dust, more than 30 percent of the beta particles radiated toward the support will be scattered back.

Table 7.12. Maximum Range $R_{\beta(max)}$ of Beta Particles in Air, in Biological Tissue, and in Aluminum as a Function of their Energy[29]

$E_{\beta(max)}$ McV	1 in Luft cm	2 $R_{\beta(max)}$ in biologischem Gewebe mm	3 in Aluminium mm
0,1	10,1	0,158	0,050
0,2	31,3	0,491	0,155
0,3	56,7	0,889	0,281
0,4	85,7	1,35	0,426
0,5	119	1,87	0,593
0,6	157	2,46	0,778
0,7	186	2,92	0,926
0,8	231	3,63	1,15
0,9	261	4,10	1,30
1,0	306	4,80	1,52
1,25	406	6,32	2,02
1,50	494	7,80	2,47
1,75	610	9,50	3,0!
2,0	710	11,1	3,51
2,5	910	14,3	4,52

Key: 1--In air; 2--In biological tissue; 3--In aluminum. Note: The values given for biological tissues can also be used for water.

In combination with the statements in sections 7.1.1 and 7.1.2 we can say the following by way of summary.

Beta radiation as a component of residual nuclear radiation has a relatively low ionization capacity but a considerably greater penetration capacity than alpha radiation. The practical range of the beta particles in air amounts to several meters, in biological body tissue it amounts to several millimeters, and in denser materials it amounts to a few millimeters. This is why beta radiation, like alpha radiation, primarily constitutes a danger in case of incorporation or also when the beta-active materials directly reach the skin, especially the mucosae. As outside radiation it is of less interest under combat conditions because it is mostly absorbed by clothing and protective gear and is kept away from radiation-sensitive body parts.

As the age of the fission product mixtures increases, there is also an increase in the relative biological danger from beta radiation because of the enrichment in long-lived radionuclides. This is why one cannot take absolute radioactivity as the sole criterion for possible damage to persons. In case of nuclear weapon detonations outside the dense atmosphere, the beta particles (electrons) form artificial radiation belts (see Section 6.4) which can continue for hours and days and in unusual cases even considerably longer.

If a space weapon flies through such a radiation belt, there will be a very hard braking radiation (x-rays) during the process of braking of the beta particles, which can damage human beings or which can also destroy electronic components or put them out of action.[30]

7.1.4.3. Gamma Radiation

Many alpha-active and beta-active radionuclides are still excited after the emission of alpha particles or beta particles and emit this surplus "residual energy" in the form of gamma radiation.

Gamma radiation (γ-radiation) is an electromagnetic wave radiation. It consists of individual quantums (energy packages) of a certain energy. Like any electromagnetic radiation, gamma radiation is propagated at the speed of light.

The gamma radiation emitted by a certain radionuclide is characteristic for it because it is not distributed over a continual energy spectrum but rather because the individual gamma quantums have very specific discrete energies. For example, the radionuclide Al-27 upon each beta decay emits a gamma quantum with an energy of 1.8 MeV, the radionuclide Na-24 emits two gamma quantums with an energy of 1.37 or 2.75 MeV.

The gamma spectrums of the radionuclides of fission products or radioactive detonation products in general however in many cases are more complicated and partly are not yet fully known.

Because the gamma quantums, in contrast to the alpha and beta particles, have neither a rest mass nor an electric charge, their interaction with a substance is also quite different. While the charged alpha and beta particles transmit their energy in portions to the envelope electrons in the course of many individual ionization processes, the gamma quantums give off their total energy either in one act or in a few reciprocal processes. But there is little probability that there will be such a reciprocal interaction, contributing to the attenuation of gamma radiation, per unit of distance, with the electrons of the atomic envelope. This is why the gamma quantums have a great range as a function of their energy.

Because the reciprocal processes between gamma quantums and the envelope electrons were explained in detail already in the description of instantaneous nuclear radiation in Section 5.3.1, something which as we know involves the Compton, photo, and pair formation effects, we need not go into this problem complex in any greater detail here.

Concerning attenuation in an absorber, gamma radiation strictly follows the exponential law:

$$I_\gamma = I_{0,\gamma} \cdot e^{-\mu d} \tag{7.13}$$

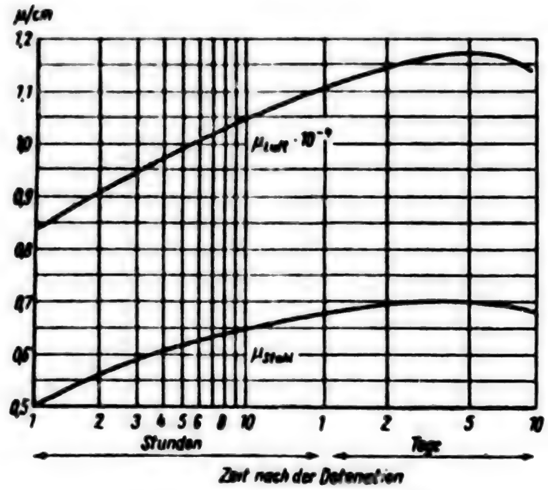


Figure 7.13. Reference values for the linear attenuation coefficient μ of gamma radiation from fission products as a function of the time after detonation. Key: 1--Hours; 2--Days, 3--Time after detonation; 4--Air; 5--Steel.

For practical calculations, we can use the formulas in Section 5.3.2.1. But because the average energy of gamma radiation of residual nuclear radiation differs from that of instantaneous nuclear radiation and because it also changes with the passage of time after detonation, we must insert the corresponding values both for the linear attenuation coefficients and for the effective half-life layers.

Section 7.3 will in greater detail cover some problems resulting from the fact that the radioactive detonation products are present as area source.

Summarizing, we can say this:

Gamma radiation as a component of residual nuclear radiation has extraordinarily great penetration capacity. It therefore can act even on crew members in armored combat vehicles and on persons in shelters. During combat operations in radioactively contaminated areas it represents the absolutely greatest danger in the form of outside radiation.

This is why, under field conditions, the computations for the evaluation of the nuclear radiation situation are primarily based on the dose rate or the dose of gamma radiation.

Review Questions

7.1. What are the factors that, after nuclear weapon detonations, determine the quantity and properties of the developing radioactive detonation products? Describe the three types of radioactive detonation products.

7.2. Describe the most important properties of the fission product mixture and interpret the data in Table 7.3.

7.3. How do the cumulative activity and the cumulative dose rate of fission products change with the passage of time after detonation? What is the significance of the assumption of a direct proportionality between the change in radioactivity and in the dose rate?

7.4. What practical conclusions spring from the constant change in the composition of the fission product mixture?

7.5. Why do certain difficulties come up in an attempt at a generalizing evaluation of neutron-induced radioactivity? What do they consist of?

7.6. Explain the principle of neutron capture.

7.7. What radionuclides can the induced radioactivity of air, water, and the soil be primarily traced back to? Interpret the data in Table 7.9.

7.8. What differences result between the fading of radioactivity of fission products and that of the induced radionuclides in the soil? Compare the energy ratios.

7.9. What peculiarities result from underground detonations regarding the composition and distribution of radioactive detonation products?

7.10. What is the significance of the unfissioned part of the nuclear charge regarding the overall radioactivity and the overall effect of the radioactive detonation products.

7.11. Describe the fundamental properties of alpha, beta, and gamma radiation.

7.12. Why do we get a different sequence in the case of external radiation and in the case of incorporation regarding the relative biological danger deriving from the individual types of nuclear radiation?

7.2. Propagation and Distribution of Radioactive Detonation Products

7.2.1. Radioactive Fallout Zones

In almost all detonation types, a more or less large part of the radioactive detonation product is expelled into the earth's atmosphere. The phenomena of the propagation and distribution of these detonation products are very multilayered and complicated. Depending on the prevailing high-altitude weather situation, the radioactive particles can cover large distances during short intervals of time. The composition and concentration of radioactive detonation products in the atmosphere as well as their geographic distribution constantly change in the course of these processes. All of these processes are very closely tied to the dynamics of the general zonal circulation of the earth's atmosphere. This is why the prognosis or evaluation of the radioactive contamination of the terrain resulting from nuclear weapon detonations is not only a physical but much more a weather problem in the broadest sense.

To describe the overall process of radioactive fallout from nuclear weapon detonations, a large number of general and special theories and models was developed in recent years.[31] Nevertheless, the current status of fallout prediction is not yet satisfactory and many problems remain to be solved. However, in this section it is neither our intention to develop a "general

theory" of radioactive precipitation, nor do we want to intrepret many statistics needed in evaluating radioactive contamination of terrain. Instead, the following statements center around those problems which characterize the significance of residual nuclear radiation as a possible main annihilation factor and their full understanding is absolutely necessary to derive the corresponding conclusions for the protection of units in case of operations in radioactively contaminated areas. This objective starts with the idea that it is impossible under the conditions of a complicated nuclear radiation situation to tie the commanders to simple and rigid rules as they make their decisions--without understanding the overall interrelationships.

Many factors influence the character of radioactive contamination of the atmosphere and the earth's surface. They include the following:

The detonation intensity and the detonation type of a nuclear weapon;

The cumulative initial radioactivity of the radioactive detonation products and their decay during the passage of time after detonation;

The distribution of radioactivity in the form of radioactive particles in terms of size and altitude at the moment of the detonation cloud's stabilization.

The direction and velocity of high-altitude winds that influence the propagation of the detonation cloud and the fallout of radioactive particles from it at the moment of detonation and at the place of detonation and in the course of its propagation at the particular places and the particular times;

The appearance of natural precipitation in the form of rainfall or snow which can speed up the deposit of radioactive substances;

The influence of vertical air currents as well as the terrain relief and the vegetation cover on the distribution of radioactive substances.

It is primarily that part of the radioactive detonation products which contributes to the radioactive contamination of the atmosphere and then of the earth's surface which initially is in the fireball and later on in the detonation cloud and which rises with them.

Depending on the nuclear weapon's detonation type and detonation intensity (see Section 2.1.2), the radioactive detonation products thus get directly or indirectly into the troposphere and into the stratosphere and are stored here for some time.[32] The subsequent fallout of radioactive particles and their deposit on the earth's surface lead to the development of radioactive precipitation areas with differing surface radioactivity and dose rate.

The radioactive contamination of the earth's surface caused by nuclear weapon detonations can schematically be subdivided into three fallout zones: the zones of local (direct), continental (semiglobal), and global radioactive fallout.

The zone of local radioactive precipitation, which takes effect during the first few hours and days after a nuclear weapon detonation, includes the radioactive contamination of the immediate detonation area and in the terrain in the direction in which the detonation cloud moves off (radioactive trace) up to those distances at which there is potentially a danger of radiation damage to man in case of brief stay in the area.

The zone of radioactive fallout [precipitation] covers a deposit region all around the globe at the level of the particular geographic latitude of the detonation with an average width of 2,000-3,000 km.

For the local and continental fallout it is especially the processes taking place in the troposphere that are of interest. Radioactive particles in the troposphere fall back to the earth's surface within a few months. The bulk of the radioactive detonation products is concentrated in the lower part of the troposphere (up to about an altitude of 6 km). The size of the particles contributing to continental fallout is 1-5 μm.

The zone of global radioactive fallout covers large parts of the earth's surface or the entire surface of the earth. It is caused by that part of the radioactive detonation products which get into the stratosphere. Concerning worldwide stratospheric fallout it is typical that the detonation products are stored for a longer time (years) in the stratosphere, that they enter the tropopause relatively slowly, and that they are deposited from there on the earth's surface and that a homogeneous mixture of long-lived radionuclides is developed with the passage of time. The separation of the radioactive detonation products from the stratosphere depends on the geographic latitude and reveals a seasonal pattern (maximums in the middle latitudes and in the spring, minimums along the Equator and in the autumn). Both phenomena are closely tied to the average zonal wind movement. Stratospheric fallout consists of the very smallest particles ($d < 1 \mu m$).

The disruption of radioactive detonation products over the local, continental, and global radioactive fallout depends primarily on the type of detonation and the detonation intensity. Data in the literature vary greatly on that score.[33] Some figures are nevertheless given in Table 7.13.

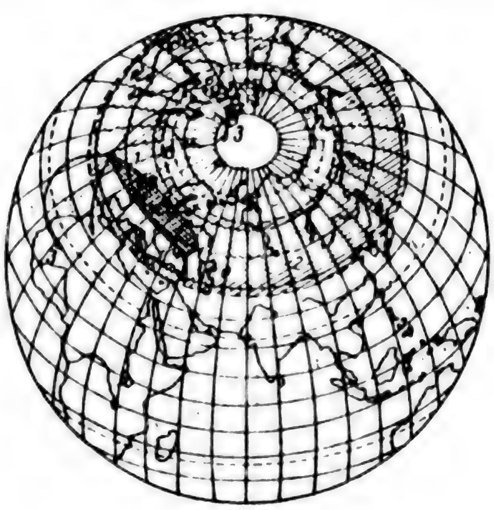


Figure 7.14. The zones of local (1), continental (2), and global radioactive fallout (3) after nuclear weapon detonations.

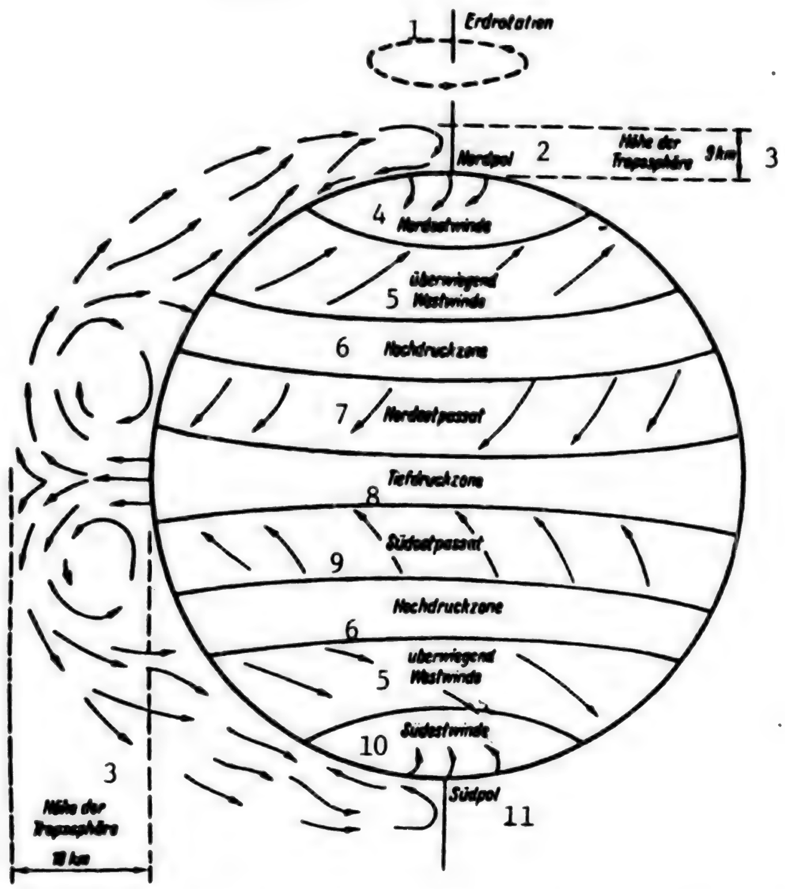


Figure 7.15. Simplified diagram illustrating the zonal circulation of the earth's atmosphere.[34] Key: 1--Earth's rotation; 2--North Pole; 3--Altitude of troposphere; 4--Northeast winds; 5--Prevailing west winds; 6--High-pressure zone; 7--Northeast tradewind; 8--Low-pressure zone; 9--Southeast tradewind; 10--Southeast winds; 11--South Pole.

Table 7.13. Distribution of Radioactive Detonation Products over the Individual Fallout Zones as a Function of the Type of Detonation and Detonation Intensity

Art der Detonation 1	2 Anteil am Gesamtniederschlag/%		
	3 lokaler Niederschlag 4	kontinentaler Niederschlag 5	globaler Niederschlag
6 Höhendetonationen	–	–	100
7 hohe Luftdetonationen			
8 kt-Bereich	1	9	90
9 Mt-Bereich	–	1	99
10 niedrige Luftdetonationen	10	30	60
11 Erddetonationen			
8 kt-Bereich	70	20	10
9 Mt-Bereich	60	20	20
12 Wasserdetonationen			
8 kt-Bereich	20	60	20
9 Mt-Bereich	20	10	70
13 unterirdische Detonationen (mit äußerer Wirkung)	80	20	–

Key: 1--Type of detonation; 2--Share out of total fallout, %; 3--Local fallout; 4--Continental fallout; 5--Global fallout; 6--High-altitude detonations; 7--High-altitude air bursts; 8--kt range; 9--Mt range; 10--Low-altitude air bursts; 11--Ground bursts; 12--Water detonations; 13--Underground detonations (with external effect).

Figure 7.15 illustrates the zonal circulation in the earth's atmosphere in a greatly simplified manner. This overall circulation however is disturbed in that individual high-pressure and low-pressure regions take shape over various areas on the earth's surface. Because, as we know, the air masses are generally shifted from areas of high air pressure to areas of low air pressure, we get spatially differing air currents with varying directions and intensities.

Regardless of that we can say that the Central European area is located in a zone with prevailing winds from the western directions (about 75 percent for annual average) with an average velocity of 40-50 km hr^{-1}. This leads to the conclusion that there is a great probability that we have a general propagation tendency for the radioactive traces running a west-east direction.

The average wind velocities have a tendency to increase with the altitude. This increase is generally typical but it varies for the individual geographic latitudes and seasons. Because of that, radioactive detonation products generally spread all the faster, the higher the detonation cloud rises; that is to say, the greater particular detonation intensity is (Figure 7.16).

The radioactive particles of the detonation products which constitute continental fallout circle the globe once in about 4-7 weeks, in a west-east direction, in the middle latitudes.

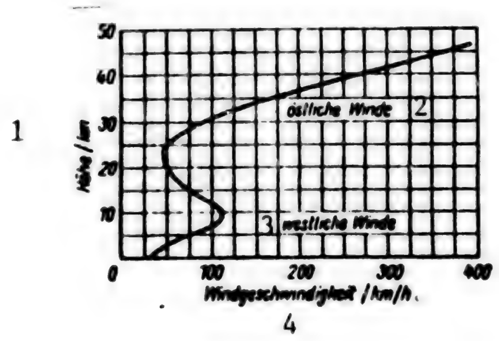


Figure 7.16. Average wind velocity as a function of the altitude over the earth's surface for the middle geographic latitudes.[35]
Key: 1--Altitude; 2--East winds; 3--West winds; 4--Wind velocity, km/hr.

On 1 March 1955, the United States on the Nevada test range conducted a nuclear weapon detonation in the Megaton range. As a result of that test, radioactive fallout came down over England between 8 and 10 March, over Greece and Turkey on 11 March, in the European part of the Soviet Union on 13 and 14 March, and in the Far East of the Soviet Union on 16-19 March.

At the end of 1963, after the entry into force of the Agreement on the Suspension of Nuclear Weapon Tests in the Atmosphere, in Outer Space, and under Water, signed by the Soviet Union, the United States, and Great Britain, the total radioactivity of the stratosphere in the northern hemisphere of the globe was something like 20 MCi and then dropped steadily (if one disregards the tests conducted by France and China). Data on the average time spent by radioactive particles in the stratosphere are presently still contradictory. It was assumed originally that annually only about 10 percent of the radioactive particles present in the stratosphere would again reach the earth's surface within a year; more recent research results show that the average half-life periods, at altitude of more than 25 km, are between 2 years (polar regions) and 4 years (Equator region) and that they are analogously between 0.5 and 3 years at altitudes below 25 km.

It is typical of continental fallout but even much more so of stratospheric global fallout that it involves mostly long-lived radionuclides (for example, Sb-125, Ce-144, Pm-147, Sr-90, Y-90, Rh-106, Ru-106, Cs-137). The composition of the radionuclide mixture in the atmosphere changes only in the course of radioactive decay processes.

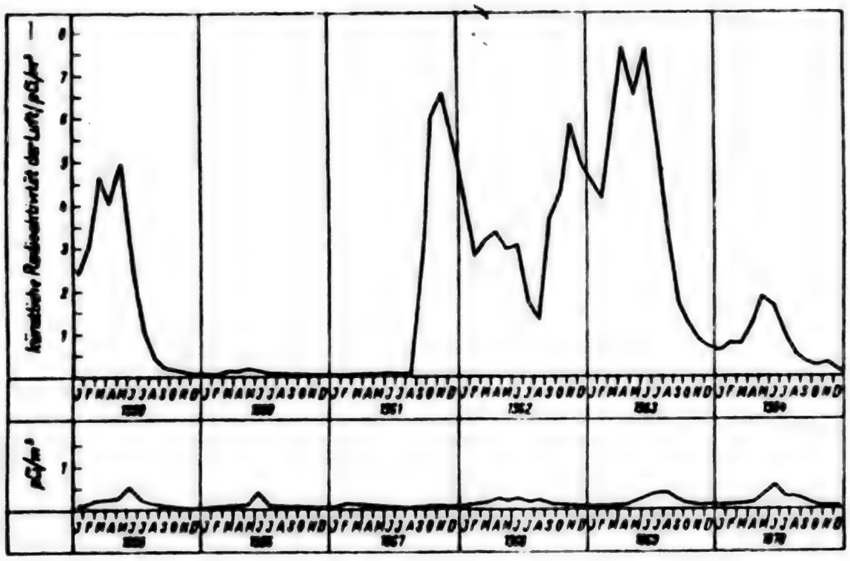


Figure 7.15. Radioactivity in the air layer near the ground in the GDR, caused by nuclear weapon detonations, in the years 1959-1970 (mean value from measurements at nine stations).[36] Key: 1--Artificial radioactivity of the air, pCi/m^2.

The global deposit of radioactive detonation products does not take place uniformly but reveals a dependence on the geographic latitude. The concentration in the northern hemisphere is considerably greater than in the southern hemisphere. According to available data, the maximum is to be found in the middle northern latitude. The biggest threat from worldwide radioactive fallout resides in the enrichment of certain long-lived radionuclides through biocycles in the human body.

Once reaching the earth's surface, the radioactive substances are absorbed by the upper ground layers, they are taken in by the plants in the process of metabolism, and they thus get directly from the plant into the human body or only through a detour via the animal body or the animal product (for example, milk). Other incorporation sources are the consumption of radioactive water and the inhalation of radioactively contaminated air.

During periods of increased nuclear weapon tests in the atmosphere, the "underground radiation" in various parts of the world subsequently increased by more than 50 percent compared to the natural radiation level. The content of strontium-90 in the bones of English pasture sheep in 1954-1956 rose from one to six units. The average strontium-90 content of milk in the United States rose from 4 units in 1954-1955 to 5-9 units in 1957 and, if nuclear weapon tests had been continued in the atmosphere unhindered, it would have reached a value of 20-30 units in 1970.

As we know, strontium-90 is enriched particularly in the bone. Because it is close to calcium in chemical respects, it gets into the body skeleton via the same routes as the latter. The beta radiation emitted here by strontium-90 among other things can lead to leukemia, bone sarcomas, and cancer because the bone marrow is one of the most radiation-sensitive tissues of the human body.

The accumulation of strontium-90 and cesium-137 can cause an increase in the irridiation of germ cells. This can cause the birth of children who will suffer from so-called incurable inherited diseases (diseases of the CNS, the hematopoietic system, appearance miscarriages [monsters], etc.).

These are just a few examples which however are suitable in clearly presenting the overall problem complex of the global radioactive contamination of the earth.[37]

From the military angle we are interested above all in local radioactive fallout within the context given here. This is why we will in the following segment take a detailed look at local terrain contamination as a function of the type of detonation.

7.2.2. Local Radioactive Terrain Contamination as a Function of the Type of Detonation

7.2.2.1. Radioactive Terrain Contamination after Ground Bursts

7.2.2.1.1. General Viewpoints

After ground bursts, the radioactive contamination of the terrain becomes a main annihilation factor. Due to the fireball's contact with the ground, a part of the soil or other materials found there will melt or will be vaporized at the place of detonation and is swept up into the fireball. This is why there is a close mixing of the radioactive detonation products in the fireball with slag, dust, and water vapor.

As the fireball cools off and as the detonation cloud is formed (condensation cloud), the nonvolatile radionuclides will be condensed first, followed later by the volatile ones. The gaseous fission products escape condensation. But among the noble gases, we find some radionuclides with an extremely short half-life whose daughter products are nonvolatile and therefore are condensed immediately after they develop. Radioactive aerosol particles of differing size are formed already as a result of these processes. Due to the effect of turbulent air currents, smaller particles can be deposited together with larger ones. This coagulation capacity depends among other things on the chemical and physical structure of the particles.

In addition we have the reciprocal interaction between radioactive particles and the inactive admixtures of the fireball or the detonation cloud. These particles in the first group originate from the condensation of the vaporized soil. They include the nonvolatile radionuclides and are more or less homogeneously distributed.

In contrast to that, the particles in the second ground have a quasicrystalline structure (at most only the surface is melted) and they are radioactive because of the deposit of easily volatile radionuclides and their daughter products. This among other things can be explained by saying that the rapid rise of the fireball and the attendant suction causes additional quantities of earth masses to be swept up from the crater and its immediate vicinity

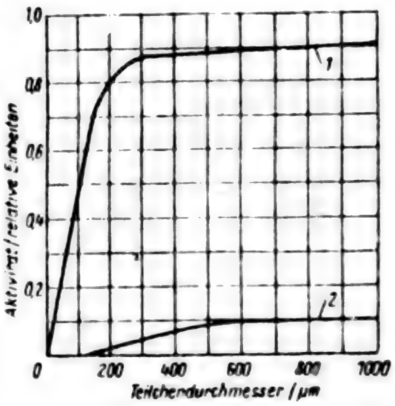
and all this material likewise gets into the condensation cloud to a certain extent. The detonation cloud's stem develops in this fashion.

The detonation cloud from a nuclear weapon detonation contains particles of differing size and physical as well as chemical structure due to complicated processes. The particle size spectrum is in the range of 0.01-1,000 μm. The share of particles of a certain size category cannot be clearly fixed and depends very much on the specific detonation conditions.

By way of reference values one may assume that, in case of ground bursts, the mass of radioactive particles will have diameters between 50 μm and 200 μm. After air bursts, about 90 percent of the particles will have a diameter of $d < 10$ μm. But it is not true that the large particles also contain the major portion of radioactivity. Instead, the overall radioactivity is distributed unevenly over the individual size categories. After ground bursts, about 12 percent of the initial radioactivity are found in particles with a diameter of $d \geqq 200$ μm, 30 percent have a diameter of $200\ \mu m > d \geqq 100\ \mu m$, 38 percent have particles with a diameter of $100\ \mu m > d \geqq 50\ \mu m$, and 20 percent have a diameter of $d < 50$ μm.

The particle size of the radioactive detonation products in the detonation cloud decreases from the base of the cloud toward the peak. About 10-20 percent of the total radioactivity are concentrated in the "stem," the rest is found in the "mushroom cap" of the detonation cloud.

1



2

Figure 7.18. Radioactive contamination distribution as a function of the particle size in the "condensation cloud" (1) and in the "stem" (2) of the detonation cloud.[40]
Key: 1--Radioactivity, relative units; 2--Particle diameter, μm.

Particles which are bigger than 1 mm will fall back to the earth directly in the detonation area and in its vicinity. As for the rest, the fallout process is an extraordinarily complicated phenomenon. Zier points out that, according to the law of Stokes, spherical particles with the density of water require about 50 minutes to fall through the troposphere from an altitude of 12 km with a diameter of 1,000 μm, about 10 hours when d = 100 μm, about 1 month when d = 10 μm and about 10 years when d = 1 μm.[38]

But the density of the radioactive particles is about 2.2-2.8 times the density of water. This results in a faster fallout velocity.

Fuchs investigates the fallout of particles from the cloud and mentions the force of gravity, the air resistance, the horizontal wind field, the vertical exchange due to turbulent diffusion, and the interaction with precipitation elements such as rainfall and snow as essential influencing magnitudes.

In this connection he shows that Stokes' law--which is used in many publications to interpret the fallout times of radioactive particles from the clouds--can no longer be used for particles where $d > 100\ \mu m$. But we cannot go into any greater detail on these problems.[39]

Figure 7.19 shows a fallout time diagram for particles of differing size. It can however be used only for the altitude range of the troposphere; as for the rest, it is in the nature of a greatly simplified model.

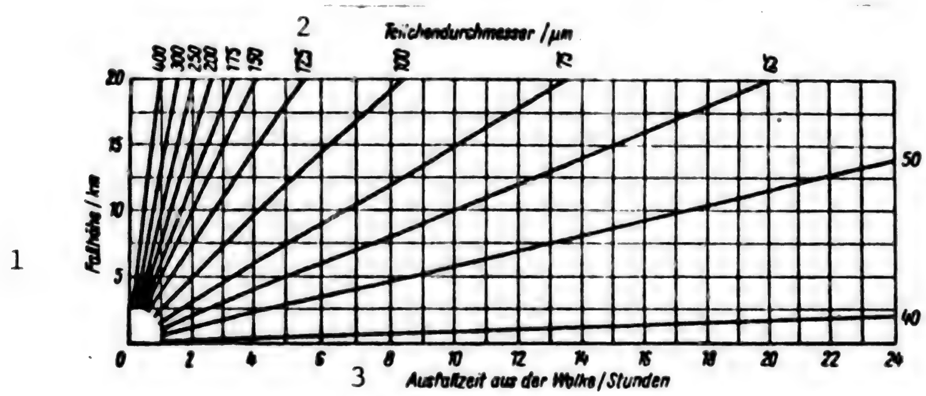


Figure 7.19. Guidance values for fallout times of radioactive particles of a certain magnitude from various altitudes.[41] Key: 1--Drop altitude, km; 2--Particle diameter, µm; 3--Fallout time from the cloud, hours.

If, except for the gravity and the horizontal wind movements, one neglects all other influencing magnitudes and if one further assumes that the wind direction and wind velocity are the same from the top of the detonation cloud to the earth's surface, then the radioactive particles will drop from a certain altitude as a function of the air density with a certain velocity toward the earth's surface and they will at the same time be shipped horizontally over a certain distance due to the influence of the wind field. The particular deposit point of the corresponding particle on the earth's surface will then be the result of both movements.

For the conditions defined, the magnitude of the horizontal propagation s of a particle at a wind velocity of v as a function of the fallout time t_{Ausf} [fallout] is equal to:

$$s = v \cdot t_{Ausf} \tag{7.14}$$

Assuming that $t_{Ausf} = h:w$, whereby h is the fallout height of the particle and 2 its average fallout velocity, it follows finally that:

$$s = v \frac{h}{w} \tag{7.15}$$

From these simple considerations we can derive some model concepts which are illustrated in Figure 7.20.

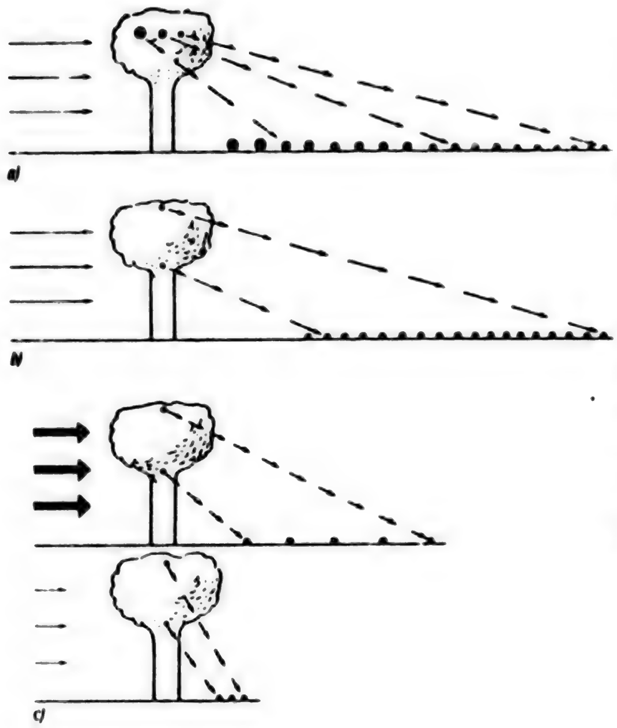


Figure 7.20. Influence of particle size, fallout height, and wind velocity on deposit pattern of radioactive detonation products on the earth's surface.
a--Particles of varying size but identical fallout height are deposited at various distances from ground zero;
b--Particles of identical size but different fallout height are deposited at various distances from ground zero;
c--In case of fast wind velocities, particles of identical size are deposited at greater distances than in case of slow wind velocities.

From what we have said so far we can summarize as follows:

In the case of ground bursts, particles of identical fallout time will be deposited in the direction of propagation of the radioactive detonation cloud at one and the same distance from the detonation place. Because these may involve particles which come from various altitude layers, they can have various sizes.

Regardless of that there is a tendency to the effect that, as the distance from the detonation place grows, the number of small (light) particles in the overall spectrum will constantly go up. The deposited radioactive particles in their entirety form a continuous fallout surface, the so-called radioactive trace.

Because under real conditions however the wind field in the rarest cases will be completely homogeneous and because the radioactive particles upon falling through the individual altitude layers are therefore subjected to different wind directions and wind velocities and because vertical exchange processes and other processes may be superposed on this mechanism, we can say that the size and shape of the radioactive trace and the maximum dose rates, appearing in each case at the same distances, will be widely different in the individual cases.

This is why one must--regardless of the basic theoretical content of a certain prediction system for the anticipated radioactive fallout--always start with the idea that considerable differences are possible between the theoretically calculated values and the really developing trace. In this connection, the reciprocal relationship between forecasting (analytical evaluation) and nuclear radiation reconnaissance assumes great significance.

The individual models for fallout prediction accordingly can be broken down into vectorial and nonvectorial systems, depending on how they consider the specific high-altitude wind conditions. The advantage of the vectorial systems consists in the fact that, even in case of complicated wind conditions, they relatively accurately reflect the real fallout region if the required initial data for the nuclear weapon detonation and the high-altitude weather situation are available. Their disadvantage rests primarily on the fact that they require relatively much work and that they as a rule permit only inadequate information as to the apparent dose rates and the anticipated radiation exposures.

In contrast to that, the nonvectorial prediction systems do not define any radioactive "coverage area" but instead start with a so-called average wind. This average wind is, in terms of direction and intensity, the kind of wind whose influence on the trace formation will be approximately equal to the vectorial sum of the wind components in the individual high-altitude layers from the top of the detonation cloud to the earth's surface. In conjunction with this average wind, we then match up the longitudes and latitudes of the radioactive traces with the individual detonation intensity. This makes it possible to illustrate the anticipated radioactive decontamination density of the terrain as a function of the distance from the detonation place and ultimately enables us to make statements as to the level of maximum dose rates, the radiation exposures of the troops while staying in and going through radioactive traces, etc. But since, along with the shape of the radioactive trace, there is also a change in its surface content and thus in the terrain's radioactive contamination density, we must realize that this kind of method is very inaccurate if the high-altitude wind directions vary greatly and that it can even fail under extreme wind conditions. These considerations likewise underscore the role and significance of nuclear radiation reconnaissance once again.

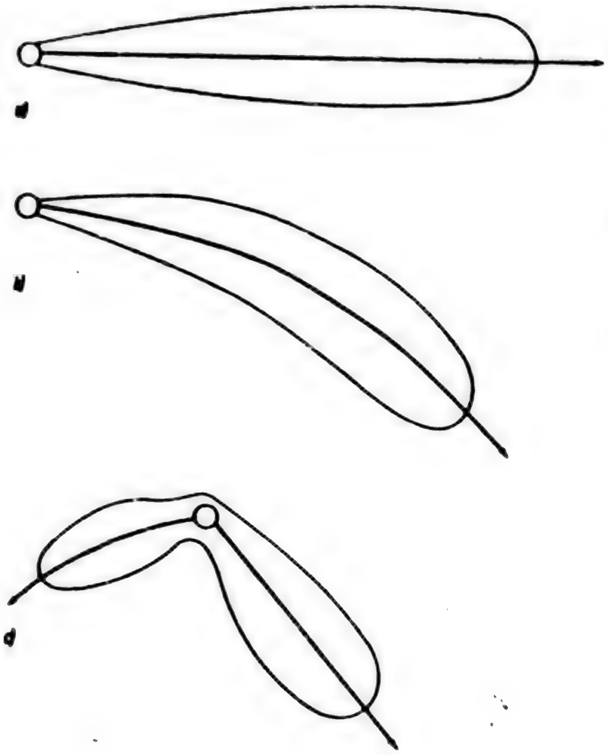


Figure 7.21. Shape of radioactive trace as a function of the high-altitude weather situation. a--Uniform wind direction at individual altitudes; b--Different wind directions at individual altitudes; c--In case of prevailing, greatly differing wind directions with fast velocities at the individual altitudes.

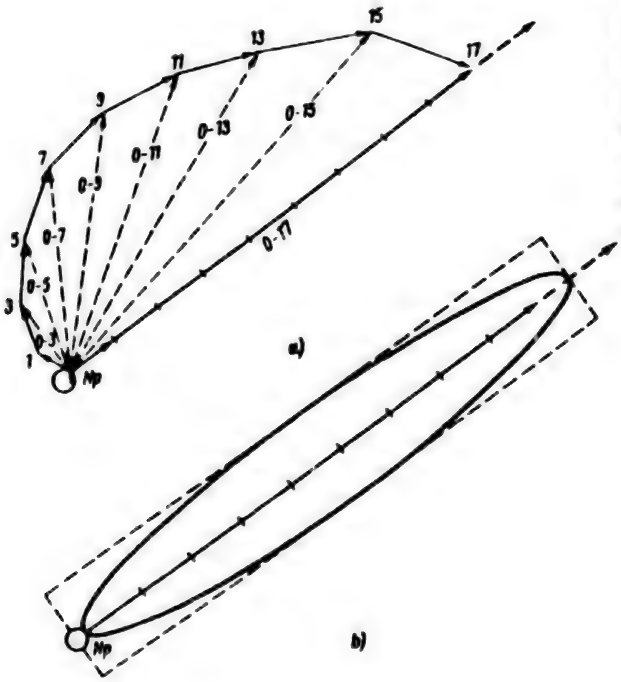


Figure 7.22. Comparison of the determination of the location and dimension of the radioactive trace with the help of a vectorial "coverage area" (a) and using as basis the average wind and a "standard surface" of specific dose rate or dose (b).

Figure 7.22a shows the average wind vectors → (direction of the arrow in the same wind direction, length of arrow equal to wind velocity) for the altitude layers of 0-1 km, 1-3 km, 3-5 km, etc. The resultants...→ give us the direction of the "average wind" for the altitude ranges of 0-3 km (0-3), 0-5 km (0-5), etc. If we start with a specific climbing altitude of the detonation

cloud and if one considers the fallout time of the radioactive particles, then, from this kind of vectorial wind diagram, one can exactly estimate or construct the radioactive fallout area with the help of the corresponding correction factors which bring about a stretch-out or pile-up.

Figure 7.22b shows only the direction of the "average wind" which here simultaneously happens to be the axis of the trace (the location of the upper edge of the cloud was assumed to be at an altitude of 17 km). The "standard surface" equivalent to the given detonation intensity--it is mostly imagined to be an ellipse or a rectangle--is superposed on the trace axis. Using method (a), the value of the correction factors must be taken from special tables while with method (b) the dimensions of the standardized trace must be taken from special tables.

The extraordinarily great influence of the high-altitude weather situation on the character of radioactive terrain contamination after nuclear weapon detonations and the related difficulties involved in a clear prediction can grow if the vertical wind profile changes rapidly with the altitude both in terms of time and in terms of space.

Table 7.14 contains some numerical data to clarify this problem complex. The resultant conclusions concerning the evaluation of radioactive terrain contamination or the nuclear radiation situation can be derived in a simple manner and are therefore not described here.

In case of high-intensity ground bursts, the radioactive trace can extend over several hundred kilometers. In this case we must expect that major deviations from the theoretically calculated propagation direction of the detonation cloud will appear due to changes in the vertical wind profile in terms of space and time. In this connection one must keep in mind that the vertical wind profile, determined during the probing of the atmosphere, will always apply only to a certain area.

Table 7.14. Examples of Major or Extreme Changes in the Vertical Wind Profile
(a) Extreme change in wind velocity with altitude (Dresden, 1 January 1966, 0000)

1	**Höhe km**	**0**	**2**	**4**	**6**	**8**	**10**	**12**
2, 3	**Windgeschwindigkeit km h^{-1}**	**7**	**45**	**60**	**85**	**175**	**215**	**130**

(The maximum wind velocity in the altitude interval considered was 9 km with $v \approx 250$ km h^{-1}. The wind directions were 270°--340°.)

(b) Major change in wind direction with altitude (Lindenberg, 23 February 1966, 1200)

1	**Höhe km**	**0**	**2**	**4**	**6**	**8**	**10**	**12**
2, 3	**Windrichtung Grad**	**90**	**160**	**250**	**240**	**220**	**210**	**260**

(At an altitude of 16 km, the wind direction was 280°. The wind velocities were in a spread of about 7-70 km hr^{-1}.)

(c) Extreme time change in vertical profile (Dresden, 10 January 1966; the data in the numerator refer to 0000, those in the denominator refer to 0600.)

1	**Höhe km**	**0**	**2**	**4**	**6**	**8**	**10**	**12**
2	**Windgeschwindigkeit**	**7**	**18**	**53**	**65**	**76**	**86**	**72**
	km h^{-1}	**15**	**25**	**72**	**53**	**36**	**32**	**40**
2	**Windrichtung**	**320**	**40**	**40**	**35**	**25**	**30**	**25**
3	**Grad**	**100**	**90**	**100**	**95**	**90**	**20**	**25**

Key: 1--Altitude; 2--Wind velocity; 3--Degree.

7.2.2.1.2. Radioactive Contamination in the Detonation Area

Ground bursts are characterized by strong radioactive contamination of the detonation area. A significant part of the radioactivity is concentrated here in the detonation crater and its immediate surroundings (see Section 2.1.3).

Terrain contamination in the detonation area of a ground burst can essentially be traced back to the fission products and to neutron-induced radioactivity.

In practical radiation calculations however one treats the entire radionuclide mixture according to the laws of fission products. As a result of this we can observe that the dose rate of gamma radiation during the first few hours after the detonation fades somewhat more slowly than described by the $t^{-1.2}$ law. The initial dose rates appearing near ground zero or in the area of the crater are so high that even a short stay outside shelters can lead to severe radiation damage or to the absorption of a lethal dose.

The shares out of the total radioactivity, which, after a ground burst, can be found in the detonation area or the radioactive trace, are determined not only by the factors already mentioned but also by the soil structure. Thus the diameters of the radioactive particles, which develop after detonation over or on sandy soils, on the average are definitely greater than those over clayey or rocky soils.

Up to about 20 percent of the radioactive detonation products, mostly from the cloud's stem, during the latter's upward movement will fall back into the detonation area during a period of 5-10 min. In this connection, the air layer near the ground is heavily contaminated with radioactive dust for a period of up to 30 min and more.

In evaluating the terrain's radioactive contamination in the detonation area, one must furthermore keep in mind that an "additional" superposition by the radioactive trace takes place in the effective wind direction. This is why the maximum dose rates of gamma radiation differ essentially at identical distances from ground zero at the side facing toward the wind and at the side of the detonation area facing away from the wind. Some reference figures are given for the first-named area in the following graph (Figure 7.23). For comparison, the analogous values are also entered for the detonation area of a low-level air burst. They apply to the entire detonation area.

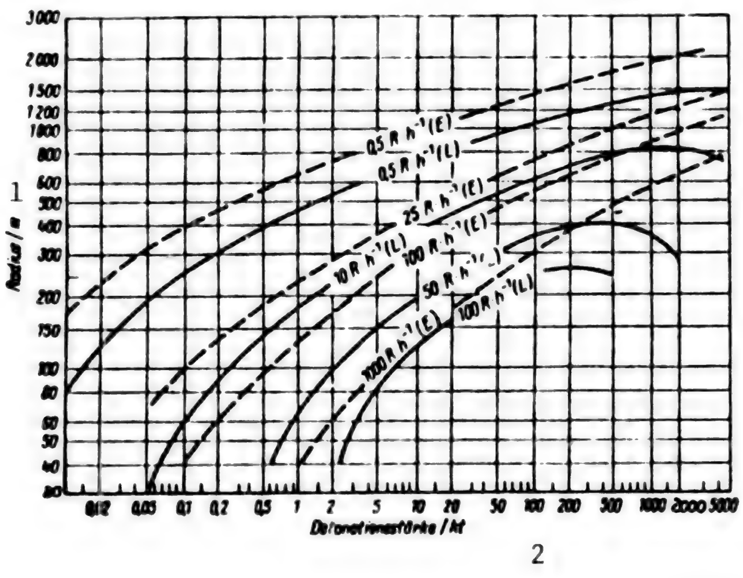


Figure 7.23. Radii of radioactively contaminated zones with a certain dose rate in the area of a ground burst (on the side facing toward the wind) and in the area of a low-altitude air burst, related to 1 hour after the nuclear weapon detonation.[42] Key: 1--Radius; 2--Detonation intensity.

As we can see from the graphic illustration, the radii of zones of identical dose rate grow only slowly as the detonation intensity goes up. As a result of radioactive decay of detonation products, these boundary lines are then shifted closer and closer to ground zero.

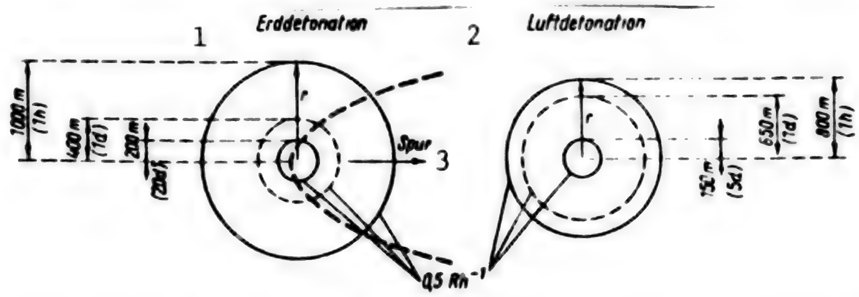


Figure 7.24. Location of the 0.5 R hr^{-1} boundary line at various times after detonation in the area of 20-kt ground and low-altitude air burst.
Key: 1--Ground burst; 2--Air burst; 3--Trace.

7.2.2.1.3. Radioactive Contamination in the Trace

As you can see already from what we said in Section 7.2.2.1.1, the radioactive contamination of the detonation area after ground bursts is immediately joined in the high-altitude wind direction by a likewise heavily radioactive region, the so-called radioactive trace.

The radioactive trace is a strip of radioactively contaminated terrain in the direction in which the detonation cloud moves off; it originates due to the fallout of radioactive detonation products (fission products). The dimensions of the traces depend on the detonation intensity and the high-altitude wind conditions and are on the order of 10^1 to 10^3 km in length and 10^0 to 10^2 km in width. By the terms "axis of the trace" we mean an imaginary line in the trace's longitudinal direction which runs across points with maximum dose rate at the particular distance from ground zero.

As the outer limit of the radioactive trace we assume a particular dose rate of 0.5 R hr^{-1}. The maximum dose rates along the axis of the trace can reach values of 10^4 R hr^{-1} at great detonation intensities and short distances from ground zero immediately after the formation of the trace.

As the basic model for the radioactive trace we take an elliptical-cigar-shaped surface which as we know however takes shape only on the assumption that the wind in the altitude range concerned has practically the same direction.

The ratio between the length and width of the radioactive trace is variable and is roughly in an interval of 5:1 to 20:1.

The radioactive trace takes up a particularly large surface after ground bursts in the Megaton range. For example, a ground burst with an intensity of q = 15 Mt--which the United States set off on 1 March 1954 on Bikini Atoll--severely contaminated a surface area of about 50,000 km^2. The gamma radiation dose rate was so great on an area of more than 1,000 km^2 that all persons, who might

have stayed outside shelters here, would have been exposed to a lethal dose at the most 4 days after detonation. The development of the radioactive trace depends on the average wind velocity. Here, we assume proportionality between wind velocity and movement speed of the radioactive particles. For the start of radioactive fallout at a certain distance from ground zero in the wind direction, the following therefore applies:

$$t_{Niederschlag} = r : \bar{v} \quad h \tag{7.16}$$

[Niederschlag--fallout]

If r/km is the distance from ground zero and $\bar{v}$/km h^{-1} is the velocity of the average wind.

The duration of radioactive fallout at a certain distance from ground zero is determined by a whole series of factors. The most important factors are the detonation intensity, the velocity of the average wind, and the distance from ground zero itself. Satisfactory generally-valid and simple mathematical derivations for the determination of the fallout duration are presently not known. The numerical values given in the literature vary from minutes to hours. But because we are primarily interested here only in the area of the radioactive trace, in which high initial dose rates appear, one may well assume that, after nuclear weapon detonations in the kiloton range, the fallout duration along the axis of the trace will be about 10-20 min. Here the dose rate during the first 5 min will rise particularly strongly. As the distance from ground zero grows, the fallout duration in general will increase and at a distance of 100 km can amount to more than half an hour.

On the other hand, the fallout duration at the individual distances will be shorter as the average wind velocity increases.

In case of dose rate measurements during the duration of radioactive fallout one must keep in mind that, during this span of time, the processes of dose rate increase due to the deposit of radioactive particles and of decrease in the dose rate as a result of radioactive decay will be superposed. Measurement results of this kind therefore can be used only by virtue of their information content (the dose rate rises rapidly, the dose rate has reached its maximum, etc.).

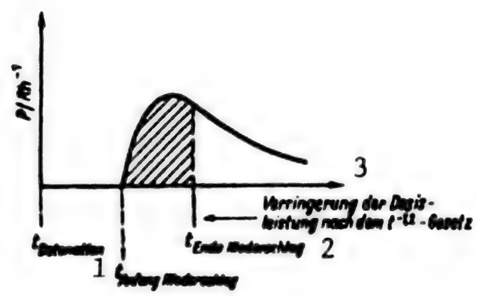


Figure 7.25. Simplified illustration of the change in dose rate at a point during radioactive fallout. Key: 1--Start of detonation; 2--End of detonation; 3--Decrease in dose rate according to t^{-12} law.

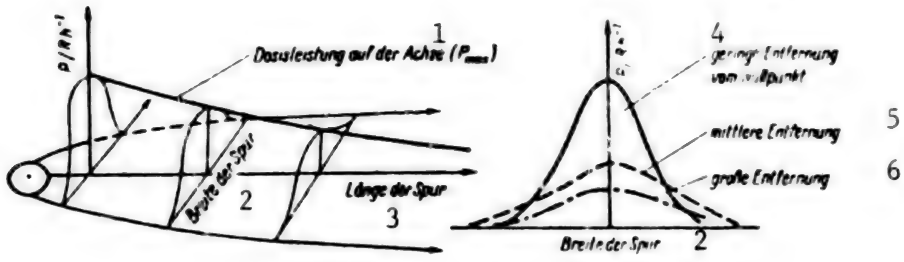


Figure 7.26. Change in maximum dose rate and dose rate profiles perpendicularly to the trace axis with the distance from ground zero. Key: 1--Dose rate of axis; 2--Width of trace; 3--Length of trace; 4--Short distance from ground zero; 5--Medium distance; 6--Great distance.

If we have a fully-developed radioactive trace, the dose rate has a tendency to decline continually along the trace axis and laterally to it as the distance from ground zero grows. But that is only a tendency here because, in case of complicated wind conditions, we might run into "islands" of high dose rate, embedded in areas of low dose rate, at various ranges. Figure 7.26 shows the spatial change in the magnitude of the dose rate in case of a simple trace in the form of longitudinal and lateral profiles. We can see that the dose rate profile, looking at it at a right angle to the trace axis, changes constantly with the distance from ground zero. The greater the distance from ground zero, the smaller will be the differences between the maximum dose rates on the trace axis and the dose rates in the trace itself. Because the limit of the trace of local radioactive fallout in the military sense is defined at 0.5 R hr^{-1}, its position changes constantly due to radioactive decay and the region thus radioactively contaminated will shrink more and more after detonation.

There are basically two possibilities for plotting the radioactive traces of nuclear weapon detonations: plotting dose rate zones and plotting dose zones.

In the first case, the dose rate limits drawn reproduce only a momentary state and do not permit any direct conclusions as to the existing or anticipated radiation exposures of the troops.

In the second case, as we draw dose boundaries, we are dealing with fictitious boundary lines within which we can expect a certain dose exposure in terms of time. These boundary lines do not change their position with the passage of time after detonation but in this way we cannot illustrate the dynamics of terrain radioactive contamination changes and the uninitiated will find it difficult to decide what degree of danger exists in what areas.

Specific data as to the dimensions of the radioactively contaminated zones and the level of the dose rates or the so-called "integral nuclear radiation doses" will not be given as we go on. Reference is made in this connection to the corresponding regulations.[41]

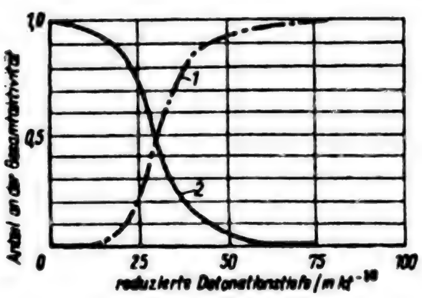
7.2.2.2. Radioactive Contamination of the Terrain after Underground Detonations

As we can see from what we have said so far in describing the phenomena and effects of underground detonations, the interaction between the blast wave and light radiation, on the one hand, and the ground, on the other hand, is even more intensive in this type of detonation than after ground detonation. This is why one must also expect some unusual features regarding the terrain's radioactive contamination. The detonation depth here exerts the greatest influence.

In case of underground blasts, the terrain's radioactive contamination is essentially of a local nature. There is no radioactive contamination of the atmosphere at all. There are primarily two causes which are responsible for this. First of all, the particle spectrum is greatly shifted towards the mm range because of the close mixing of radioactive detonation products with the earth masses expelled from the detonation crater; besides, the climbing altitude of the detonation cloud is considerably lower than after ground bursts of the same intensity. This is why the detonation products fall back to the earth's surface much faster, this is why the surface area of the region covered by radioactive fallout is smaller, and this is why the radioactive contamination density of the terrain goes up.

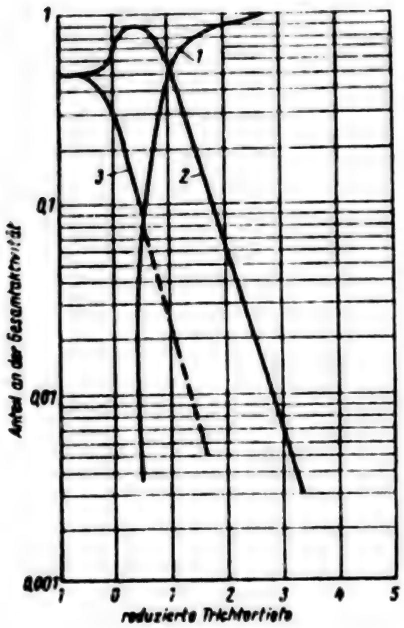
Under combat conditions, we encounter certain difficulties in evaluating the terrain contamination caused by a specific underground detonation to the extent that the dimensions of the contamination zones are a complex function of the detonation intensity and the detonation depth. These initial data cannot always be clearly determined. The two illustrations below (figures 7.27 and 7.28) present a general overview of the distribution of radioactive detonation products after underground nuclear weapon detonations.

1



2

Figure 7.27. Distribution of radioactive detonation products as a function of the reduced detonation depth.[44]
1--Radioactivity bound in the earth;
2--Radioactivity contributing to the radioactive contamination of the earth's surface or the atmosphere.
Key: 1--Share of total radioactivity;
2--Reduced detonation depth, m kt^{-30}.



1

2

Figure 7.28. Distribution of radioactive detonation products as function of the reduced crater depth. Reduced crater depth--quotient from detonation depth and depth of visible crater; 1--Share of radioactivity trapped in melt; 2--Share of radioactivity deposited in the crater or its immediate vicinity; 3--Share of radioactivity contributing to the radioactive fallout at greater distances from the place of detonation. (The area of 1-0 given in the abscissa pertains to ground bursts; in other words, a positive detonation altitude.) Key: 1--Share out of total radioactivity; 2--Reduced crater depth.

Figures 7.27 and 7.28 show us that, as the detonation depth increases, the share of radioactivity bound in the area of the crater will grow considerably. This is due specifically to the neutron-induced radioactivity in the crater, the radionuclides trapped directly in the melt, and the detonation products which again fall back from the detonation cloud into the crater or its immediate vicinity. In this context we might once again point out that a so-called base cloud is formed in the detonation area from the little dust particles falling out of the detonation cloud and that base cloud is likewise heavily radioactive; it lasts as long as about 1 hour and extraordinarily severely restricts visibility conditions.

In summary we can say this:

The radioactive contamination of the terrain after underground nuclear weapon detonations is characterized by the fact that we get an extraordinarily heavily radioactive crater and a pronounced radioactive trace with high dose rates. The dose rates in the area of the crater pileup are still between 10^3 and 10^6 R hr^{-1} even 1 hour after the detonation. The dimensions of the radioactive trace, after detonations between 0.01 and 50 kt, depending upon the detonation depth, are between 10 and 100 km in length and between 1 and 20 km in width. The developing dose rates at the same distances are 10 times higher than after ground bursts of identical intensity.

The statements made here clearly show that underground detonations have an enormous barrier effect not only because of their powerful crater formation but because of their extraordinarily high terrain contamination. At dose rates of 10^3, 10^4, or 10^5 R hr^{-1} 1 hour after the detonation, assuming that radiation begins at this moment, the lethal dose is absorbed already within 0.5 hour,

5 minutes, or several tens of seconds. It follows from this that in areas with such high dose rates unit operations are absolutely impossible during the first few hours after detonation. But, for example, Engineer operations will still be extraordinarily hindered even days later and will be possible, if at all, only by working in shifts.

This is why one can say in conclusion that, after underground nuclear weapon detonations, terrain contamination cannot only become a main annihilation factors but, under certain conditions, exceeds all other annihilation factors in terms of their effect.

7.2.2.3. Terrain Contamination from Air Bursts

In case of air bursts, terrain contamination as a rule recedes far behind the other annihilation factors and therefore does not decisively influence unit operations. But it is wrong to think that a radioactive fallout area can develop only after ground and underground detonations and that the appearance of radioactive fallout, regardless of the dose rate level, always points to this kind of detonation type.

Normally, of course, the dose rates appearing at the individual ranges from the place of detonation in the direction in which the detonation cloud moves away will differ very essentially from those after ground bursts. They are generally lower by a factor of 10^3 to 10^4. But one can draw clear conclusions from this fact directly after the start of fallout only on the assumption that, among other things, the required initial data for the particular enemy nuclear strike are known.

Other things being equal, the character of anticipated terrain contamination depends on the detonation altitude also in case of air bursts. They therefore differ consierably from each other in case of low and high air bursts.

Radioactive contamination in the detonation area of air bursts is caused primarily by the neutron-induced radioactivity. The radioactively contaminated terrain represents a circular surface around ground zero whose size as well as initial dose rates are determined by the detonation intensity, the detonation altitude, and the soil composition. This radioactive contamination of the detonation area is significant above all after low-altitude air bursts. Reference might be made here to the previously given numerical values (Figure 7.32). This is why it is not necessary at this point to go into any greater detail regarding this problem complex.

The character of radioactive terrain contamination after air bursts is decisively influenced by the fact that the dust column, swept up from the earth's surface, usually does not reach the condensation cloud or partly merges with it only at a point at which the formation of the radioactive aerosol particles has already been essentially completed. Accordingly, the detonation cloud from an air burst, as we explained in Section 7.2.2.1, contains mostly very small radioactive particles. Only a part of that can merge with dust particles from the stem of the detonation cloud to form larger particles and thus falls back to the earth's surface relatively quickly. If a trace with

noteworthy dose rates is to form in this fashion, then it must be observed, in contrast to ground and underground detonations, that the maximum initial dose rates after completion of radioactive fallout appear only at a certain distance from ground zero. This means that there can be a quasi-contaminated or only slightly contaminated region between the radioactively contaminated region of the detonation area and that area.

Air bursts cover a relatively wide altitude range; it is therefore possible to define a so-called fallout-proof detonation altitude for them. It can be interpreted as the minimum altitude at which one need not expect a trace to be formed with a very high degree of probability. The trace formation can be estimated numerically from the following relation:

$$H_{m} = 100 \cdot q^{1/3} \quad m \tag{7.17}$$

This shows that low-altitude air bursts are below the fallout-proof detonation altitude while high-altitude air bursts are above it (see Section 2.2.2.1).

The detonation altitude to be expected in the specific case among other things depends on the hardness of the target hit and low-altitude air bursts frequently produce optimum effects; this is why one must in this connection also figure that there will be a certain radioactive fallout which will not fail to have an influence on unit operations in these areas.

One must furthermore keep in mind that, regardless of the basic estimate of the character of terrain contamination after air bursts, one can also get contaminated areas with relatively high dose rates if there is a massing of such strikes or if they are followed by atmospheric precipitation in the form of rainfall or snow. This is why the evaluation of radioactive terrain contamination calls for commanders and staffs to devote their full attention to this also after air bursts. In this respect one must likewise not draw any unjustified conclusions, above all when the initial or reconnaissance data are inadequate.

7.2.3. Influence of Weather and Terrain Conditions on Propagation and Distribution of Radioactive Detonation Products

In addition to the influence of high-altitude wind conditions on the movement and deposit of radioactive detonation products covered earlier, there are other factors which have an effect here. That includes weather conditions in general and the terrain relief as well as its vegetation cover. Although there are very few specific data in the literature on this problem complex, it is necessary to entertain some elementary considerations on this subject.

It was pointed out earlier that fallout can cause the dose rates in the radioactive trace to rise considerably above the "normal values." This is due to the fact that, in case of rainfall or snow, the radioactive particles of varying size are deposited on raindrops or snowflakes or act as condensation nuclei. In case of heavy rainfall, for example, drops with a diameter of 3 mm require a drop time of 10-15 min even from greater altitudes. If therefore there is rainfall or snowfall shortly after a nuclear weapon detonation,

the radioactive particles will be washed out of the air and will quickly hit the earth's surface. As a result of that, the radioactive detonation products are concentrated on a relatively small surface area. One may assume that the dose rates in the trace in this way can rise to a multiple, on the average.

This washout process is important above all in conjunction with small detonation intensities ($q < 5$ kt) where the detonation clouds do not rise above the maximum altitude of rain clouds which 6 km. does not read.

On the other hand, fallout also influences the distribution of radioactive substances over the earth's surface. In case of heavy rainfall, the radioactive particles are washed off the objects in the terrain, the plants, and the earth's surface, they partly penetrate into the soil, or they flow off with the water. Along with this, there is a natural radioactive decontamination of certain terrain sectors while the dose rates can rise in depressions and valleys. Furthermore, fallout will bind the radioactive dust, will cleanse the air in the layer near the ground, and will thus considerably reduce the danger of incorporation and permit personnel to remain also in areas with higher dose rates or without wearing the mask. In the winter, heavy and long-lasting snowfall will "make it easier" to get through heavily contaminated terrain sectors since a compact and thick snow blanket will lead to a corresponding attenuation of nuclear radiation.

A powerful surface wind can, in case of dry weather and terrain not covered with vegetation, lead to a redistribution of radioactive substances. The air layer near the ground is enriched with dust and the latter can penetrate into the cabins and combat compartments of combat vehicles. Under these conditions, the combat vehicles and technical combat equipment will be heavily contaminated during march movements and personnel will likewise be exposed to the danger of incorporation.

Although the terrain relief regarding the distribution of radioactive detonation products by no means has the same influence as on the behavior of chemical warfare agents, one must nevertheless expect that there can be locally different radioactive contamination conditions. For example, one may assume that, as the wind flows over rises in the terrain, the radioactive particles will be deposited more on the side facing toward the wind than on the side facing away from it.

Depending upon the terrain's vegetation cover, the wind-braking effect of the vegetation cover makes itself felt more or less strongly. A part of the radioactive substances will be deposited in forests in the treetops and will thus lead to a reduction in the effective dose rate immediately along the surface of the ground.

In case of troop movements in heavily overgrown but contaminated terrain, there is a danger that the soldiers might come directly into contact with radioactively contaminated grass, branches, etc. This is why protective clothing must be worn in these cases, regardless of the dose rate level. These few examples might suffice to explain the overall problem complex.

Review Questions

7.13. Explain why exact statements on the character of terrain contamination due to nuclear weapon detonations are connected with difficulties in individual cases.

7.14. What are the factors that influence the propagation of radioactive detonation products?

7.15. Define local, continental, and global radioactive fallout.

7.16. Explain the differing distribution of radioactive detonation products over the individual fallout zones as a function of the type of detonation and the detonation intensity.

7.17. What are the semistrategic and tactical conclusions resulting from the fact that westerly winds prevail in the elevation range primarily involved in Central Europe?

7.18. Why does the detonation cloud from a nuclear weapon detonation contain radioactive particles of varying structure and size?

7.19. What essential influencing magnitudes determine the fallout times of radioactive particles from certain altitudes?

7.20. Describe the process of trace formation as a function of the type of detonation.

7.21. Why does the radioactive trace from a nuclear weapon detonation have an elliptical shape only in special cases?

7.22. What do we mean by the direction and velocity of the "average wind?" How is it determined and what problems are connected with its practical application?

7.23. Compare the radioactive decontamination of the detonation areas from ground, underground, and air bursts.

7.24. How does the detonation depth influence terrain contamination after underground detonation?

7.25. What is the significance of terrain contamination after air bursts?

7.26. Interpret the concept of "fallout-proof" detonation altitude.

7.3. Connection between Surface Radioactivity, Dose Rate, and Dose in Zones Contaminated by Nuclear Weapon Detonations--Basic Calculations on Terrain Contamination

Combat operations in zones contaminated by nuclear weapon detonations expose the troops to a certain radiation and the danger of incorporation of

radioactive substances and require commanders and staffs constantly to have a comprehensive overview of the existing terrain contamination and to perform comprehensive calculations to evaluate the nuclear radiation situation.

For this purpose, it is necessary to have a mastery of the corresponding basic calculations and it is necessary to spell out uniform principles of work organization.

In this section we want to explain the most important connections between surface radioactivity and the dose rate and the dose of gamma radiation in an elementary fashion. These points are supplemented in practical terms in Section 7.4 in connection with the coverage of the necessary protective measures for units during operations in radioactive zones.

Radioactive contamination of the terrain as we know can be traced back to fission products, neutron-induced radioactivity, and the unfissioned part of the nuclear charge. In most detonation types, these individual radiation sources are superposed in this connection, especially in the detonation areas. But because calculations under field conditions must be simple and as fast as possible, it is impossible in practice to distinguish all theoretically imaginable contamination cases.

This is why we can say the following:

For radiation calculations under field conditions, we basically consider the fission products as the cause of terrain contamination, with the exception of the detonation area involved in air detonations. Calculations for the detonation area connected with air detonations are based on the neutron-induced radioactivity. The unfissioned part of the nuclear charge as a rule is not considered.

This problem complex is once again illustrated schematically in Figure 7.29.

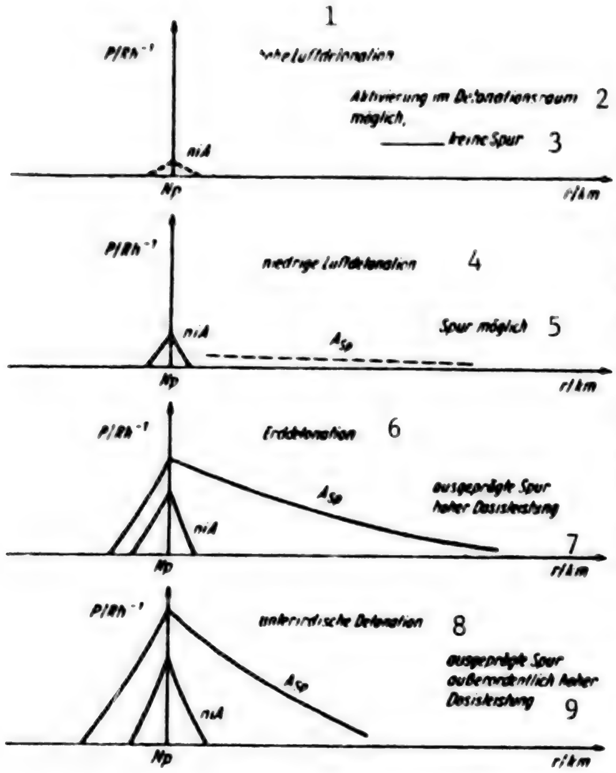


Figure 7.29. Sources of residual nuclear radiation for the various detonation types (not drawn to scale). niA--Neutron-induced radioactivity; A_{Sp}--Radioactivity of fission products; Np--Ground zero.
Key: 1--High-altitude air bursts; 2--Radioactive contamination possible in detonation area; 3--No trace; 4--Low-altitude air burst; 5--Trace possible; 6--Ground burst; 7--Pronounced trace with high dose rate; 8--Underground detonation; 9--Pronounced trace with extraordinarily high dose rate.

7.3.1. Trace from Nuclear Weapon Detonation as Radioactive Surface Source[46]

In simplified theoretical investigations of radioactive terrain contamination one considers the radioactive fallout area as a rule as a level, homogeneous surface [area] source without any inherent absorption over which we get a radiation field of gamma and beta radiation. The following statements are confined exclusively to problems connected with gamma radiation. Here, the dose rate is related to an altitude of 1 m above such a surface [area] source.

For purposes of derivation and for the better understanding of the laws of the radiation field above the radioactive trace as an area source, we had best first of all start with a point-shaped gamma radiation source.

Each gamma radiation source can be characterized by its radioactivity. The basic unit of measure of radioactivity is the Curie (Ci). The following applies: $1 \text{ Ci} = 3.7 \cdot 10^{10}$ decay processes per second. The connection between radioactivity A of a point-shaped radiation source, which emmits gamma radiation, and the dose rate of this gamma radiation P at a range r from the source in the air shapes up as follows:

First of all, the dose rate generated is directly proportional to the radioactivity of the radiation source:

$$P \sim A.$$

Second, the dose rate of gamma radiation, if we assume uniform propagation, decreases in an inversely proportional fashion to the square of the distance from the source:

$$P \sim \frac{1}{r^2}$$

Third, the attenuation in the air is superposed on this quadratic decrease of the dose rate with the distance and, using the linear attenuation coefficient μ, we get the following:

$$P \sim e^{-\mu t}$$

Neglecting a possible multiple scatter of gamma radiation, we finally--by introducing the proportionality factor k_γ, called the dose constant, and considering the size relationships between the units of measure used--get the following equation:

$$P = \frac{A \cdot k_\gamma}{r^2} e^{-\mu r} \qquad (7.18)$$

P--Dose rate of gamma radiation, R hr^{-1}
A--Radioactivity of point-shaped radiation source, Ci
R--Distance from radiation source in air, m
μ--Linear attenuation coefficient for air, m^{-1}
k_γ [illegible]--Dose constant of gamma radiation, R m^2 Ci^{-1} hr^{-1}

(For fission products, we can take the corresponding numerical values for k_γ and μ from figures 7.5 or 7.13. But, before insertion into Formula 7.18, they must be converted to the basic magnitudes required above. For this purpose it is necessary to multiply the values for k_γ with the factor 10^{-1} and for μ with the factor 10^2.)

The dose constant k_γ is a measure of the energy of the emitted gamma quantums and its percentage share per decay process. The following applies to the calculation of the dose constant of the fission product mixture as function of the time after detonation:

$$k_\gamma = 0{,}536 \sum_{i=1}^{n} p_i \cdot E_i \qquad (7.19)$$

k_γ--Dose constant, R m^2 Ci^{-1} hr^{-1}
p_1--Number of gamma quantums of certain energy per decay process
E_1--Energy of these gamma quantums in MeV.

Because Formula 7.18 does not allow for the scatter of gamma radiation in the air, it can be used in this form only for relatively shor distances from the radiation source. For accurate calculations it is therefore necessary to introduce a "buildup factor" B which will allow for the multiple scatter and we then get the following relation:

$$P = \frac{A \cdot k_\gamma}{r^2} e^{-\mu r} \cdot B \tag{7.20}$$

The magnitude of the buildup factor can approximately be calculated as follows:

$$B = 1 + 0{,}5\mu \cdot r + 0{,}015\mu^2 \cdot r^2 \tag{7.21}$$

if μ are inserted im m^{-1} and r in m.

On the basis of these relations between radioactivity, dose rate, and distance from the source--defined for a point-shaped gamma radiation source--we can find the transition to the similar laws pertaining to an area source.

Corresponding derivations in this connection are given among others by Fuchs[47] and Spencer.[48] But in order somewhat to simplify the treatment of this problem complex in the space available here, we will, as we go on, take out multiple scatter in the air as well as back-scatter of gamma radiation along the boundary surface between the earth and the air. In this connection, reference is made to the work by Spencer.

We now look at the dose rate P (Figure 7.30) at altitude h above the center of a circular, uniformly radioactively contaminated area with a radius R at a given area of radioactivity A_F. The following applies:

$$A_F = \frac{A}{F}; \quad [A_F] = \frac{\text{Ci}}{\text{m}^2} \quad \text{or} \quad \frac{\text{decays}}{\text{min cm}^2} \tag{7.22}$$

The contribution of an area element dF, considered as a point-shaped radiation source, which is at distance ρ from the center of the circle, to the cumulative dose rate P can be seen in Formula 7.18 as follows:

$$dP = \frac{A_F \cdot k_\gamma}{r^2} e^{-\mu r} \cdot dF \tag{7.23}$$

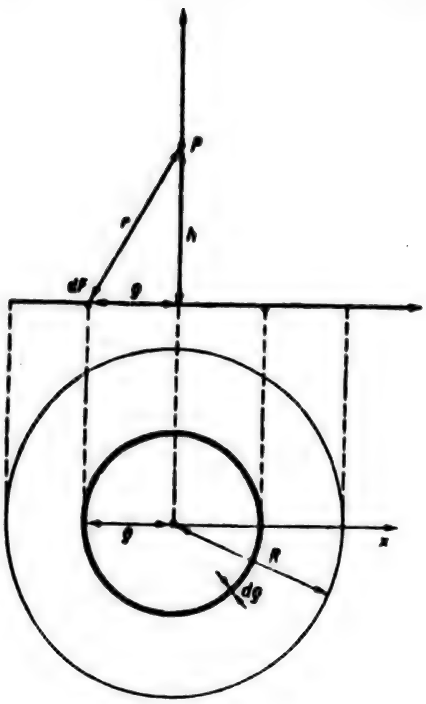


Figure 7.30. On the derivation of the dose rate of gamma radiation over the radioactive trace of a nuclear weapon detonation.

The circular ring with the differential intensity dρ for which all area elements have the same distance r as the following surface area:

$$dF = 2\pi \cdot \varrho \cdot d\varrho$$

From this we get the following for the differential dose rate at altitude h:

$$dP = \frac{A_\gamma \cdot k_\gamma}{r^2} e^{-\mu r} \cdot 2\pi \cdot \varrho \cdot d\varrho \tag{7.24}$$

From $r^2 = \rho^2 + h^2$ we find the following by means of differentiation:

$$2\varrho \cdot d\varrho = 2r \cdot dr \quad \text{and} \quad \varrho \cdot d\varrho = r \cdot dr \tag{7.25}$$

Because of 7.25 we thus get:

$$dP = 2\pi \cdot A_\gamma \cdot k_\gamma \frac{e^{-\mu r}}{r^2} r \cdot dr = 2\pi \cdot A_\gamma \cdot k_\gamma \frac{e^{-\mu r}}{r} dr \tag{7.26}$$

We get the dose rate, generated by the radioactivity of the entire circular surface with radius R, by integrating Equation 7.26 into the limits r = h to

$$r = \sqrt{R^2 + h^2}$$

$$P = 2\pi \cdot A_\gamma \cdot k_\gamma \int_h^{\sqrt{R^2 + h^2}} \frac{e^{-\mu r}}{r} dr$$

By means of substitution we can finally write the following:

$$P = 2\pi \cdot A_F \cdot k_\gamma \int_{\mu h}^{\mu \sqrt{R^2 + H^2}} \frac{e^{-r}}{\mu \cdot r} d(\mu \cdot r) \tag{7.27}$$

Using the tabulated integral exponential function[49]

$$-Ei(-x) = \int_x^\infty \frac{e^{-t}}{t} dt, \quad \infty > x > 0 \tag{7.28}$$

we get the integration:

$$P = 2\pi \cdot A_F \cdot k_\gamma \left[Ei\left(-\mu \sqrt{R^2 + h^2}\right) - Ei(-\mu \cdot h)\right] \tag{7.29}$$

P--Dose rate, R hr^{-1}
A_F--Area radioactivity, Ci m^{-2}
k_γ--Dose constant, R m^2 Ci^{-1} hr^{-1}
R--Radius of radioactively contaminated area, m
h--Altitude above radioactively contaminated area, m
μ--Linear attenuation coefficient, m^{-1}

From the course of the integral exponential function there follows for h = constant and $R \to \infty \; Ei(-\mu \sqrt{R^2 - h^2}) \to 0$, and equation 7.29 then gets the following form:

$$P = 2\pi \cdot A_F \cdot k_\gamma [-Ei(-\mu \cdot h)] \tag{7.30}$$

Because of the rapid convergence of the function n - Ei (-x), Equation 7.30 can however be used for the practical calculation of the dose rate at a height of 1 m already with adequate accuracy if R > 100 to 150 m applies to the radius of the radioactively contaminated area.

This emerges from Figure 7.31 on which is plotted the percentage share of the dose rate as a function of the circular radius of the radioactively contaminated area. One can furthermore recognize that the size of the area, which contributes a certain percentage rate to the overall dose rate, grows as the altitude of the measurement point goes up.

Under realistic conditions one can assume that the dose rate in the trace of a nuclear weapon detonation will not depend as heavily on the measurement height as indicated in formulas 7.29 and 7.30. This is due not only to the process of multiple scatter[50] in the air and the special conditions along the boundary surface between the earth and the air but it is also due to the uneven sections in the radioactively contaminated terrain. Figure 7.31 shows that, at a measurement height of 1 m, more than 90 percent of the dose rate can be irradiated in from an area with a radius of R ≈ 100 m; on the other hand, this can be the case already at a surface with a radius of R ≈ 50 m in uneven terrain. This leads to the conclusion that, in the radioactive

trace, the relative differences in the level of the dose rates of two neighboring measuring points can be all the greater, the greater the elevation differences of the terrain happen to be. In this connection one must also consider the vegetation cover and the man-made structures in the terrain. In open, level terrain, measurements at intervals of 300-500 m are generally completely sufficient, except in the case of extremely small detonation intensities and observations directions running perpendicularly to the trace axis. Under different terrain conditions, the density of the measurement points must be increased correspondingly.

One may furthermore assume that the dose rates in heavily-cut terrain will be somewhat less along hill tops than in larger valleys.

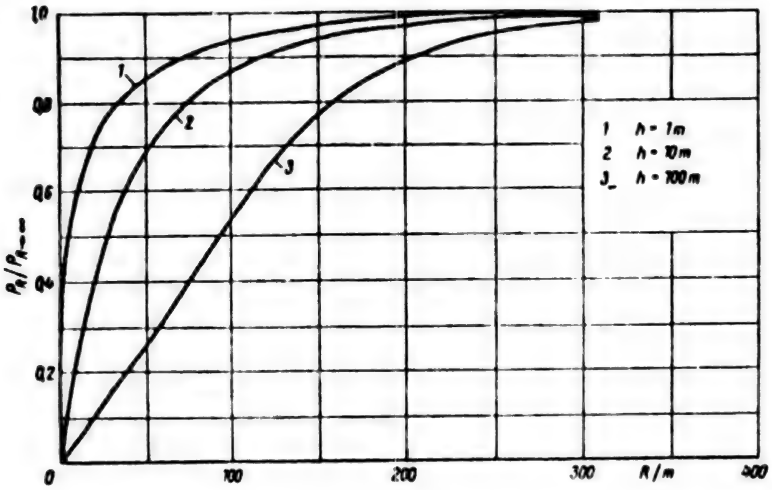


Figure 7.31. Ratio $P_R:P_{R\to\infty}$ as a function of the radius of the radioactively contaminated area.

On the basis of the known connection between area radioactivity and dose rate it is possible to put together some easily handled formulas. But when we use them we must clearly realize that the anticipated accuracy is poor and that detailed statements therefore on this point make little sense.

The Curie has already been defined as the basic magnitude of radioactivity at:

$$1 \text{ Ci} = 3.7 \cdot 10^{10} \text{ decay processes per second.}$$

From this we get the following for the area radioactivity

$$\begin{aligned} 1 \text{ Ci m}^{-2} &= 3{,}7 \cdot 10^{10} \text{ Z s}^{-1} \text{ m}^{-2} \\ &= 2{,}22 \cdot 10^{12} \text{ Z min}^{-1} \text{ m}^{-2} \\ &= 2{,}22 \cdot 10^{8} \text{ Z min}^{-1} \text{ cm}^{-2} \end{aligned}$$

As we established earlier, an area radioactivity of 0.1 Ci m^{-2} corresponds to a dose rate of 1 R hr^{-1}, measured at a height of 1 m above the earth's surface in the central part of a sufficiently large area radioactively

contaminated by fission products during the first 2-3 days after detonation, so that we get the following from this relation:

$$1 \text{ R h}^{-1} \triangleq 2.22 \cdot 10^7 \quad \text{Z min}^{-1} \text{ cm}^{-2}.$$

From this we get the following in general:

$$A_F \approx 2 \cdot 10^7 \cdot P \quad \text{Z min}^{-1} \text{ cm}^{-2} \qquad (7.31)$$

if the dose rate P is inserted in R hr^{-1}.

The radioactive contamination of combat vehicles and combat equipment will generally be smaller by a factor of k; that is, smaller than the earth's surface. Here the values of k will particularly depend on whether or not we are dealing with an already developed radioactive trace and what the weather conditions are.[51]

$$A_{F(\text{equipment})} \approx 2 \cdot 10^7 \cdot P_{\text{terrain}} \cdot k \text{ Z min}^{-1} \text{ cm}^{-2} \qquad (7.32)$$

Binding statements as to the radioactive contamination of the air layer near the ground over a well-developed radioactive trace are difficult to make because many factors influence this development. The volume radioactivity (radioactivity concentration) of the air will be particularly high during the movement of convoys in dry weather on unimproved roads or at relatively high wind velocities.

In these cases, the volume radioactivity A_V can be on the following orders of magnitude:

$$A_V \approx (10^2 \ldots 10^4) \cdot P_{\text{terrain}} \text{ Z min}^{-1} \text{ l}^{-1} \qquad (7.33)$$

The order of magnitude of the concentration of radioactive fission products in small, open, stagnant waters in the radioactive fallout area, whose average depth does not exceed 10 m, can be estimated as follows on the basis of the dose rate of the area radioactivity measured along the banks:

$$A_V \approx \frac{2 \cdot 10^8 \cdot P}{h} \approx \frac{10 \cdot A_F}{h} \quad \text{Z min}^{-1} \text{ l}^{-1} \qquad (7.34)$$

P--Dose rate of terrain, R hr^{-1}

A_F--Area radioactivity of terrain, Z min^{-1} cm^{-2}

h--Average depth of place in water, m.

In conclusion we might observe that, for rough practical calculations for the detonation areas of nuclear weapon detonations, the connection between area radioactivity and dose rate is not as simple to express because of the rapid spatial change in the dose rate as it is for the trace. But because this problem complex in general is hardly of any interest, we will not go into any greater detail on it here.

7.3.2. Connection between Dose Rate, Dose, and Integral Dose in Zones Whose Radioactivity Can Be Traced Back to Fission Products

The **dose rate** of gamma radiation from fission products is a function of the time elapsed since the nuclear weapon detonation and, according to Formula 7.2, Section 7.1.1, if the exponent is assumed to be n = - 1.2, follows the law given below:

$$P(t) = P_0 \left(\frac{t}{t_0}\right)^{-1,2} \qquad (7.35)$$

P9t), P_o--Dose rate at same place (under same measurement conditions) at times t or t_0 after detonation, are R hr^{-1} or mR hr^{-1}

t, t_o--Times related to detonation, hr.

If one relates the dose rate P_o to 1 hour after nuclear weapon detonation, that is to say, t_o = 1 hr, then the Formula 7.35 is simplified as follows:

$$P(t) = P_{1h} \cdot t^{-1,2} \qquad (7.36)$$

For the relation $P(t):P_{1hr}$ it then follows that we have:

$$\frac{P(t)}{P_{1h}} = t^{-1,2}$$

This function is illustrated graphically in Figure 7.32.

From $7^{-1,2} \approx 0,1$, $(7 \cdot 7)^{-1,2} \approx 0,01$, $(7 \cdot 7 \cdot 7)^{-1,2} \approx 0,001$, etc., there then follows the so-called 7-hour rule for the dose rate of fission products:

The dose rates of a terrain sector radioactively contaminated by fission products of uniform age will decline each time during a period seven times as long, always related to the moment of detonation, to 1/10 of the dose rates present during the simple time.

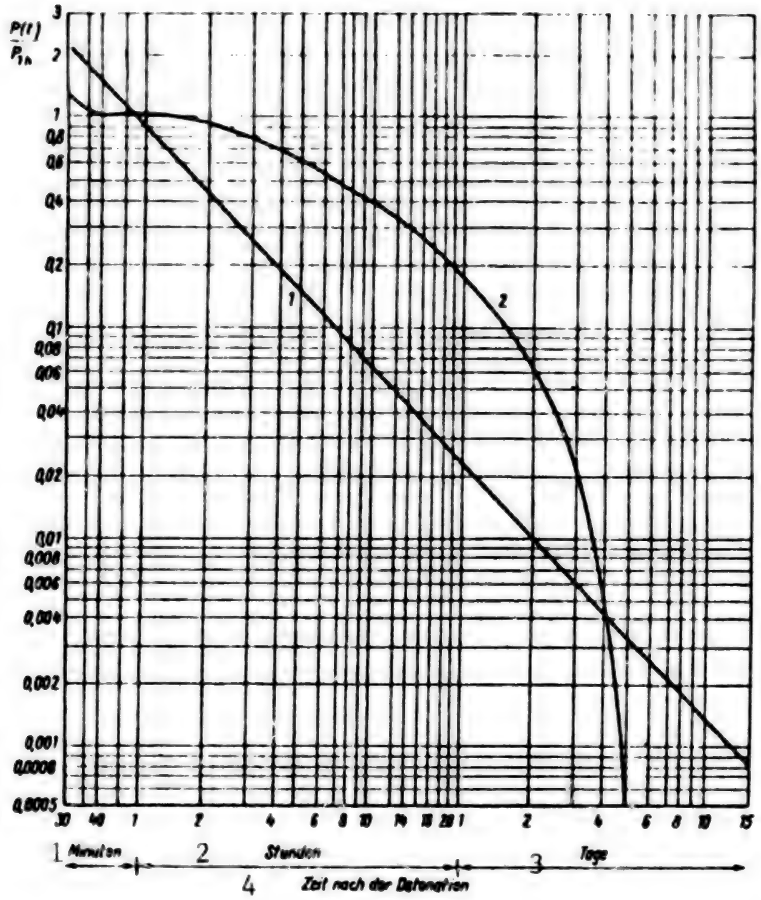


Figure 7.32. Decrease in dose rates of gamma radiation from fission products (1) and neutron-induced radioactivity (2), in each case related to the dose rates 1 hour after detonation, in the double-logarithmic illustration. (Curve (2) was entered here only for comparison purposes; it will however be discussed only in Section 7.3.3.) Key: 1--Minutes; 2--Hours; 3--Days; 4--Time after detonation.

Examples: After the expiration of a period of 1-7 min or 10-20 hrs or 2-14 days after detonation, in each case 10 percent of the dose rate of 1 min, 10 hrs, or 2 days are still present.

For more accurate calculations, Table 7.15 summarizes several 1 hr reference values according to Figure 7.32 in the form of a table.

Table 7.15. One-Hour Reference Values for Dose Rate of Gamma Radiation from Fission Products

Zeit nach der Detonation 1	$\frac{P(t)}{P_{1h}}$	Zeit nach der Detonation	$\frac{P(t)}{P_{1h}}$
15 min	5,28	5 h	0,14
30 min	2,30	6 h	0,12
45 min	1,41	8 h	0,08
1 h	1	10 h	0,06
2 h	0,44	1 d	0,02
3 h	0,27	2 d	0,01
4 h	0,19	3 d	0,006

Key: 1--Time after detonation; h--hrs.

In the course of combat operations by units in radioactively contaminated zones we are primarily interested not in the level of the existing dose rates but in the resultant radiation exposure and its effect on mission accomplishment. This is why staffs must perform the transition from dose rate to dose in evaluating the nuclear radiation situation. Three basic ways are possible here and each of them meets differing accuracy requirements. For the sake of simplicity we will therefore start with a practical example.

Problem:

The planned assembly area of a motorized rifle battalion, located in the radioactive trace of a ground burst triggered by the enemy, 1 hr after detonation reveals an average dose rate of 100 R/hr^{-1}. Here we must compute the probable dose absorption when personnel remain in this area outside shelter of any kind for 2-6 hrs after detonation.

(The protective effect offered by various types of shelter is deliberately eliminated here in order not to complicate further discussion. Besides, for methodological reasons, we calculate with the exact figures in the table although this does not always make sense under combat conditions because of the uncertainty of the initial values and because we are primarily interested here in orders of magnitude. Figure 7.33 will illustrate the problem complex we are facing here.)

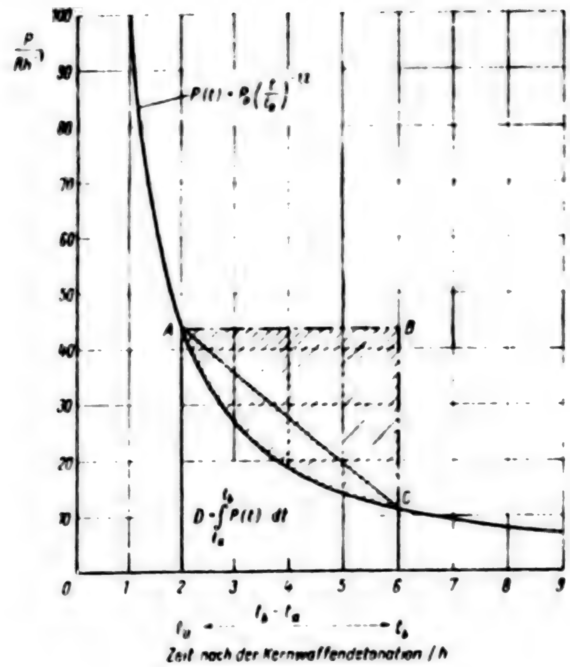


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Figure 7.33. On the calculation of dose absorption during unit operations in radioactively contaminated zones. Key: 1--Time after nuclear weapon detonation, hr.

If, in the area considered, the dose rate 1 hr after nuclear detonation is 100 R/hr^{-1}, then its reduction during the passage of time during detonation can be calculated with the help of formula 7.35 or, in this specific case, because we have P_{1h} = 100 R/h^{-1}, with the help of 7.36. But this is no longer necessary here because the required values can be taken directly from Figure 7.32 or Table 7.15. Figure 7.33 shows the decay curve drawn in this fashion. We can furthermore see or we can easily calculate (Table 7.15) that, at the start of the effective radiation (t_a = hrs), the dose rate in the planned assembly area is still 44 R/hr^{-1} and that at the time of completion (t_b = 6 hrs) it is still 12 R/hr^{-1}.

The first and simplest way to determine the nuclear radiation dose to be anticipated or absorbed while remaining in a radioactively contaminated terrain sector consists in the fact that we consider the dose rate to be constant during the time of stay $t_b - t_a$. Under this assumption we can formulate the following:

$$D = P \cdot t \text{ R, when } P = \text{const} \qquad (7.37)$$

For the numerical example selected, if we only assume the dose rate at time t_a = 2 hr to be known, we get the dose value D = 44 R/hr^{-1} x 4 hrs = 176 R.

If we try to understand this result with the help of Figure 7.33, we can easily note that the hachured area ABC above the decay curve is the part by which the calculated dose turns out to be too high.

Dose calculations according to formula D = P · t give us excessively high values because the decay of the dose rate during the radiation time is not taken

into consideration. Satisfactory agreement is achieved only if a longer period of time has already elapsed since the detonation and if the time spent in radioactively contaminated terrain is comparatively short. This is why one should restrict such calculations to those cases where we are concerned with the determination of a rough overview or where the age of the fission products is not known or where several radioactive traces are superposed.

The second way to calculate the nuclear radiation dose according to the relation:

$$D = \frac{P_1 + P_2}{2} t \quad \mathrm{R} \tag{7.38}$$

Gives us a result which is closer to the real nuclear radiation exposure but nevetheless still turns out to be too high (Figure 7.33). Here it is customary to insert for P_1 or P_2 the dose rates at the start or at the end of radiation action, also labelled P (arrival) and P (departure).

For the numerical example selected we then get accordingly:

$$D = \frac{P_{3h} + P_{6h}}{2} t = \frac{(44 + 12)\ \mathrm{R\ h^{-1}}}{2} 4\ \mathrm{h} = 112\ \mathrm{R}$$

The explanations given for formula 7.37 apply here accordingly.

The third way to calculate the nuclear radiation dose goes back to Formula 7.35 but can be used only if the age of the fission products can definitely be matched up with a certain detonation time. In this case the following applies:

The exact nuclear radiation dose during unit operations in radioactively contaminated area can be obtained by integration of the function P(t) within the limits of the time of stay $t_b - t_a$.

$$D(t) = \int_{t_a}^{t_b} P(t) \cdot dt = \int_{t_a}^{t_b} P_0 \left(\frac{t}{t_0}\right)^{-1.2} \cdot dt = P_0 \cdot t_0^{1.2} \int_{t_a}^{t_b} t^{-1.2} \cdot dt$$

$$D = 5 \cdot P_0 \cdot t_0^{1.2} \left(\frac{1}{t_a^{0.2}} - \frac{1}{t_b^{0.2}}\right) \quad \mathrm{R} \tag{7.39}$$

t_0--Time after detonation at which dose P_0 was measured, hr
t_s--[Illegible] start of radiation action, hr
$t_{[illegible]}$--End of radiation action, hr.

We can see, that under field conditions, the use of Formula 7.39 is obviously too time-consuming. This is why corresponding calculation aids--for example, the SG-1 radiation calculator--were developed and introduced. Several brief explanations will be given on this point later on.

If, for the numerical example selected, we insert the corresponding values into Formula 7.39, then we get the exact value D = 86 R for the level of the nuclear radiation dose. A comparison shows us that, in our example,

the dose calculated according to Formula 7.38 is 30 percent too high and that it is as much as 100 percent too high according to Formula 7.37. This shows us the limitations of such calculations.

Formula 7.39 can be simplified under certain conditions. Because this can give us an important insight into the relationship between dose rate and dose, we might explain some of the steps here.

The first step is based on the assumption that the radioactively contaminated terrain is not left after we have entered it, that is to say, $t_b \to \infty$. It then follows from 7.39 that:

$$D_{t_b \to \infty} = 5 \cdot P_0 \cdot t_0 \left(\frac{t_0}{t_a}\right)^{0.2}$$

If, in the second step, we assume that the moment of start of radiation action is at the same time the moment of measurement, that is to say $t_a = t_0$, then we have the following:

$$D_{t_b \to \infty} = 5 \cdot P_0 \cdot t_0 \qquad (7.40)$$
$$t_a = t_0$$

[Some symbols illegible in original]

This expression can be labelled as the so-called "integral nuclear radiation dose D_1" whereby however we must yet agree as to the reference time t_0. Just exactly how this will be handled in each individual case will depend on the particular situation; for example, a specific fallout prediction system based on dose zones. Here we might define the following:

The integral nuclear radiation dose is the dose which takes effect during a stay, in radioactively contaminated terrain, of 1 hour after detonation up to the complete decay of the radioactive fission products.

According to the definition it follows that $P_o = P_{1h} = 100$ R h^{-1} $D_1 = 5 \cdot 100$ R $h^{-1} \cdot 1h = 500$ R. Similarly, according to Formula 7.40, we get $P_0 = P_{2h} = 44$ R h^{-1} (Table 7.15) $D = t \cdot 44$ R $h^{-1} \cdot 2h = 440$ R. Between 1 and 2 hours after the nuclear weapon detonation, in this specific case, 60 R, in other words, 12 percent of the integral dose, take effect. Due to P9T :$P_{1h} = t^{-1.2}$, the last statement applies regardless of the level of the dose rate $P_{1\ hr}$ at time $t_{1\ hr}$. In other words, this means that--regardless of the dose rate level in a radioactively contaminated sector--12 percent of the integral nuclear radiation dose D_a take effect within a span of time of 1-2 hrs after detonation. This percentage distribution of the integral dose is illustrated in Figure 7.34.[52]

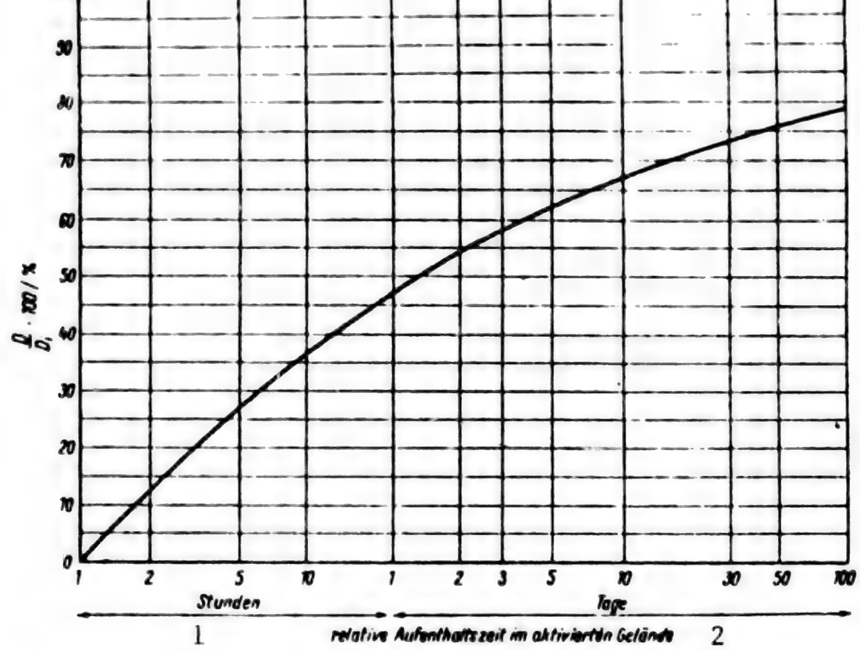


Figure 7.34. Key: 1--Hours; 2--Rel. time of stay in contaminated terrain

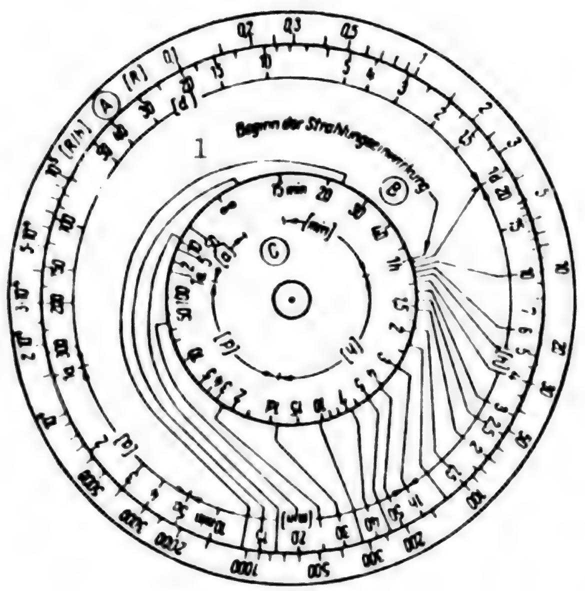


Figure 7.35. The SB-1 radiation calculator. Key: 1--Start of radiation action.

As we can see in Figure 7.34, about 35 percent-10 percent = 25 percent of the integral nuclear radiation dose take effect 2-10 hours after detonation. This generally tells us that the dose increase per unit of time is very great during the first few hours after detonation. This is why every, no matter how

short reduction of the time spent in the area or postponement in the start of operations in radioactively contaminated terrain can lead to a considerable reduction in the radiation exposure of the units.

The most important calculation aid in judging a given radioactive terrain contamination situation is the SB-1 radiation calculator based on equations 7.35 and 7.39. The following calculations are basically possible with the help of this calculation disk:

The calculation of the dose rate decrease with the passage of time;

The estimation of the detonation time of a nuclear weapon detonation;

The determination of the anticipated unit radiation exposure;

The calculation of the maximum permissible time of stay;

The estimate of the possible start or necessary completion of the stay in radioactively contaminated terrain;

Rough calculations on the area or volume radioactivity of fission products.

The SB-1 radiation calculator consists of three disks or scale rings which can be rotated against each other and which are labelled with letters A, B, and C, going from the outside to the inside.

On scale A we find plotted the dose rates (R/hr^{-1}) or the nuclear radiation doses (R) in the range of 0.1 to 100,000 (in some calculator disks, we read "100 k" instead of 100,000). This means that the scale subdivision A is used twice depending upon the type of problem to be solved.

Scale B shows a time subdivision (min--minutes, h--hours, d--days, a--years), which is related to the moment of the detonation and which serves to adjust the particular measurement time of the corresponding dose rate.

Scale C likewise shows a time division related to the moment of the detonation which is used to adjust the start t_s [illegible] or the termination t_b of radiation action. A fixed marker is used here in the form of an arrow on disk B, labelled "start of radiation action."

In the following calculation examples we will use the following symbols to abbreviate the presentation:

P_0(A)--Dose rate P_0 on scale A;
t_0(B)--Time t_0 after detonation on scale B;
$t_{[illegible]}$(C)↗ --Time of start of radiation action $t_{[illegible]}$ on scale C is adjusted to the arrow "start of radiation action" on scale B;

P_0(A)/t_0(B)--Dose rate P_0 on scale A is made to coincide with the pertinent measurement time t_0 on scale B;

(c)--(a)--Transition from scale C along or between the adjacent guidelines leading to scale A (between the guidelines, we can interpolate roughly).

Problem 1. Calculation on the Decrease in the Dose Rate with the Passage of Time after Nuclear Weapon Detonation

A dose rate of 20 R h^{-1} (P_0 = 20 R/hr^{-1} is measured in the area around a CP 2 hrs after a nuclear weapon detonation (t_0 = 2 hr).

What is the dose rate in the same area 3.5 hrs ($t_{3.5\ hr}$) and 1 day ($t_{1\ d}$) after detonation?

Solution:

20 R h^{-1}(A)|2 h (B);

Now all pertinent values are opposite each other, that is to say, $P_1|t_1$, $P_2|t_2$, etc., and they can be read off directly.

Result:

$$P_{3,5h} = 10\,R\,h^{-1};\quad P_{1d} = 1\,R\,h^{-1}$$

Note:

Naturally, we can conversely also read off the points in time, after detonation, matched up with the corresponding dose rates. In this example, a dose rate of P = 5 R/hr^{-1} is matched up with a fictitious measurement time of about t = 6 hrs.

Problem 2. Calculations on Estimating the Detonation Time of a Nuclear Weapon Detonation

On the day of detonation, 10 R/hr^{-1} are measured at 1600 and 7 R/hr^{-1} are measured at 1700 at a certain place in the radioactive fallout area following an underground nuclear weapon detonation. At what time did the nuclear weapon detonation take place?

Solution:

The solution to this problem can be found by means of trial and error.

We look for 10 R/hr^{-1} (A) and 7 R/hr^{-1} (A) and we mark these values;

The time differential is Δt = 1 hr; in other words, disk B must be rotated until this time difference turns up between both of the above-mentioned numerical values.

Result:

This condition is fulfilled when 10 R/hr^{-1} (A)/3 hrs (B) and 7 R/hr^{-1}(a)/4 hrs (B). The detonation took place around 1300, in other words, 1700 minus 4 **hrs** or 1600 minus 3 hrs.

Note:

The solution of such problems requires a certain degree of practice, but above all, it calls for systematic and deliberate trial and error. The result is not exactly accurate but is completely sufficient for rough calculations. The result must then be checked out by figuring back in accordance with Problem 1.

Problem 3. Calculations on Probable Unit Radiation Exposure

How high would be the probable dose absorption of a unit which, at a dose rate of P_{1h} = 200 R/hr^{-1} would be in this area, outside any shelter, between 2 hrs (t_s) [illegible] to 1 day (t_b) after detonation?

Solution:

- 200 R h^{-1} (A)/1 h (B);
- 2 h (C) ↗;
- 1 d (C)——(A).

Result:

On scale A we read off a nuclear radiation dose D ≈ 350 R.

Note:

If the radiation exposure is known, one can then, with the help of the tables given, determine not only the level of the anticipated casualties but also the probable time of casualties. When we are dealing with units under cover, the nuclear radiation dose determined must then be multiplied by the attenuation factor of the particular shelter. Because we have an attenuation factor of f_s = 0.1 [illegible] for tank crews, we would get a dose of D = 350 R · 0.1 = 35 R in our example.

Problem 4. Calculations on Maximum Permissible Time of Stay

At a damaged bridge in the trace of a ground burst, we measure 50 R/hr^{-1} (P_0 = 50 R/hr^{-1}) 1.5 hr after a nuclear weapon detonation (t_0 = 1.5 hr). How long can an Engineer unit work to repair the bridge, on the basis of single-shift operation, if the work is started 3 hrs after detonation ($t_{a[illegible]}$ = 3 hrs) and if an average radiation exposure amounted to a maximum of 25 R is not to be exceeded?

Solution

- 50 R h^{-1} (A)|1.5 h (B);
- 3 h (C) ↗;
- 25 R (A) — (C).

Result:

On scale C we read off the value $t_b \approx 5$ hours. Accordingly, the maximum permissible time of stay is $t_b - t_a$ = 5 hrs - 3 hrs = 2 hrs.

Note:

Under certain conditions, a maximum permissible nuclear radiation dose, the so-called command dose, can be specified for various unit operations in radioactively contaminated zones. In calculating the time of stay one must keep in mind in this connection that, before working with the calculator disk, we must also figure on the attenuation factor of covered positions or shelters. For tanks, the attenuation factor against residual nuclear radiation has the value $f_s = 0.1$. In other words, if a command dose of 10 R is specified for a tank unit, then, on scale A, we must not use the value 10 R as calculation basis, but rather value 100 R (100 R · 0.1 = 10 R). This situation is once again made clear by the example in Problem 5.

Problem 5. Calculations on Possible Start of Necessary Termination of Stay in Radioactively Contaminated Terrain

The situation estimate shows that a terrain sector to be negotiated 20 min after a ground burst (t_0 = 20 min) reveals an average dose rate of 300 R/hr^{-1} P_0 = 300 R/hr^{-1}). It was calculated that crossing this sector on foot would take 4 hrs ($t_b - t_a$ = 4 hrs, with APC's 1.5 hr ($t_b - t_a$ = 1.5 hr) and with tanks 1 hr ($t_b - t_a$ = 1 hr). The command dose is specified at 10 R in all three variants. At what points in time after detonation can crossing be started?

Solution:

(a) Crossing on foot:

- 300 R/hr^{-1} (A)|20 min (B);
10 R (A) - (C), marking on disk B through a point;
Between arrow "start of radiation action" and the point marked on B one must now, by means of trial and error, using disk C, adjust for a time difference of $t_b - t_a$ = 4 hrs [illegible];

If this has been done, then, opposite ↗ we will have the point in time t_a [illegible] and opposite the mark point we will have the point in time t_b.

(b) Crossing with APC's and tanks

The general solution is as described under (a) above. But changes come up when we work with the command dose. The command dose is 10 R. APC's have an

attenuation [protection] factor of $f_s = 0.25$. As a result of this, the calculation value of the command dose goes up to 40 R and similarly in the case of tanks it goes up to 100 R when $f_s = 0.1$.

The switch from scale A to scale C thus takes place from 40 R (A) or 100 R (A) and not from 10 R (A) as during a crossing on foot.

Result:

For crossing on foot we get: $t_a \approx 15$ hrs, $t_b \approx 19$ hrs; by APC: $t_a \approx 2$ hrs, $t_b \approx 3.5$ hrs; with tanks: $t_a \approx 30$ min, $t_b \approx 1.5$ hrs.

Note:

This problem clearly shows that the determination of the result (crossing on foot) in some cases is not quite clear. But, in looking at this problem complex, one should be guided more by tactical rather than by purely mathematical viewpoints. For example, looking at the radiation exposure level, it is as a matter of fact of no concern whether the movement on foot starts 15 or 17 hours after nuclear weapon detonation. The decisive thing is always the accomplishment of the combat mission. It must furthermore be kept in mind that the level of the particular command dose was fixed arbitrarily in the individual example.

Problem 6. Rough Calculations on Area or Volume Radioactivity of Fission Products

The area radioactivity of a combat vehicle was determined as follows:

$$A_F = 5 \cdot 10^7 \text{ Z min}^{-1} \text{ cm}^{-2}$$

It may be assumed that the fission products are 1 hour old. How great is the residual radioactivity 2 hours after detonation?

Solution:

The solution of this problem is possible on the basis of the proportionality between radioactivity and dose rate, using scales A and B. The calculation method is the same as in Problem 1. Because the radioactivity values in terms of their order of magnitude however frequently exceed the upper limit of the scale subdivision on scale A, they must be reduced by the corresponding power of 10 before we start the calculation. The result read off must then be multiplied by the same power. In the problem given here, we can make the following scale adjustment:

- $5 \cdot (10^7 \text{ A min}^{-1} \text{ cm}^{-2})$ (A)/1 hr (b);

This means that all values on scales A and B have been matched up with each other.

Result:

On scale A we read off the value $A_F \approx 2 \cdot (10^7\ Z\ min^{-1}\ cm^{-2})$ when $t = 2$ hrs.

Note:

The calculations on volume radioactivity are performed in the same manner so that more detailed explanations are not necessary.

In all of the problems explained, one would in practice always have to start with astronomic time indications and one would first have to convert them to the point in time matched up with the pertinent detonation. If one keeps in mind that this would involve smooth hourly or half-hourly values in the rarest cases, then we can clearly see that the accuracy attainable with the SB-1 radiation calculator is entirely adequate. It must therefore also become our habit to round out the determined values in a meaningful fashion in the end. If this is not done, then we are feigning a situation that does not exist in reality.

It is possible even without special computation aids or tabular values, using the known rules on the change in the dose rate and the nuclear radiation dose of the fission products, at least roughly to evaluate an existing case of terrain contamination. The most important rules are given below and are documented with numerical examples. Previously explained interrelationships are once again summarized here.

1st Rule:

The dose rate, measured at a certain place at a certain time after a nuclear weapon detonation, will decline in each case during double the time, related to the moment of detonation, to the half value reduced by 10 percent.

Example:

A dose rate of 200 R/hr^{-1} is measured 2 hrs after a nuclear weapon detonation. After double the time, in other words, 4 hrs after detonation, we can anticipate a dose rate of 100 R/hr^{-1} - 10% ≙ 100 R/hr^{-1} - 10 R/hr^{-1} = 90 R/hr^{-1}.

2nd Rule:

The dose rate, measured at a certain place at a certain time after nuclear weapon detonation, will decline in each case during thrice the time, related to the moment of detonation, to the fourth part [1/4] increased by 10 percent.

Example:

A dose rate of 200 R/hr^{-1} is measured 2 hours after a nuclear weapon detonation. After triple the time interval, in other words, after 6 hrs following

the detonation, we can expect a dose rate of 50 R/hr^{-1} + 10% ≙ 50 R/hr^{-1} + 5 R/hr^{-1} = 55 R/hr^{-1}.

3rd Rule

The dose rate, measured at a certain place at a certain time after nuclear weapon detonation, drops to half after double the time minus 10 percent.

Example:

A dose rate of 200 R/hr^{-1} is measured 2 hours after nuclear weapon detonation. After 4 hrs-10% ≙ 4 hrs - 0.4 hrs ≈ 3.5 hrs we can anticipate a dose rate of 100 R/hr^{-1}.

4th Rule

The dose rate measured at a certain place 1 hour after nuclear weapon detonation, related to the time of detonation, is still 10 percent after 7 hours, 1 percent after 2 days, and 0.1 percent after 2 weeks.

Example:

A dose rate of 200 R/hr^{-1} is measured 1 hour after a nuclear weapon detonation. Related to the point in time of the detonation, we can anticipate 20 R/hr^{-1} after 7 hours, 2 R/hr^{-1} after 2 days, and 0.2 R/hr^{-1} after 2 weeks, at the same place.

5th Rule

The nuclear radiation dose absorbed during a stay in a radioactively contaminated zone is never greater than the product of the initial dose rate multiplied by the time of stay.

Example:

Combat operations lasting 3 hours were launched 2 hours after a ground burst in a radioactively contaminated region in the trace with an average dose rate of 10 R/hr^{-1}. The effective radiation dose cannot be more than 30 R.

6th Rule: If a radioactively contaminated area is t hours after a nuclear weapon detonation and if the dose rate P_t is present at that time, then the maximum dose, during sustained stay outside shelter, will be $D = 5 \cdot P \cdot t$ roentgen.

Example:

Just 4 hours after a nuclear weapon detonation, 10 R/hr^{-1} were measured in the area of a camp. In case of sustained stay, starting 4 hours after detonation, this give us a maximum possible dose absorption of $D = 5 \cdot 10 \cdot 4$ R = 200 R.

7th Rule

If a radioactively contaminated region is entered t hours after a nuclear weapon detonation and if the dose rate P_t is present at that time, then, in case of a temporary stay outside shelter, one will receive 15 percent of the maximum possible dose calculated according to the Formula $D = 5 \cdot P \cdot t$ up to double the entry time, 20 percent up to triple the entry time, and 25 percent of the quadruple entry time.

Example:

One day after a ground burst, an average dose rate of 5 R/hr^{-1} is measured at an airfield. During a subsequent stay of up to 2 days after the detonation, 15 percent of $D = 5 \cdot 5 \cdot 24 \triangleq 15$ percent of 600 R = 90 R will take effect. Similarly, we will get $t_b = 3$ D, D = 120 R and $t_b = 4$ d, D = 150 R. Although these values primarily have a theoretical significance, they are nevertheless suitable for characterizing the existing conditions for combat operations at this airfield.

Regardless of our appreciation of the known physical laws of radioactivity, dose rate, and dose and the computation aids or tabular values built on their basis, one must not disregard the fact that, under combat conditions, especially after massive use of nuclear weapons, we can face extremely complicated conditions involving terrain contamination which cannot be evaluated according to conventional methods. One must therefore consider entirely normal all those cases in which developing radioactive fallout cannot immediately be matched up with a known detonation time but where that time must first be determined. Here in other words immediate calculations according to the $t^{-1.2}$ law and the relations and statements derived from it are not possible.

Even in case of superposition of radioactive traces of varying age, we run into difficulties because the cumulative decay of the dose rate of the fission products does not follow the $t^{-1.2}$ law. We do not want to go into detail on these problems but we nevertheless would like to provide some suggestions here for further thought.

At times it is still assumed that an estimate of terrain contamination is possible in a clear and also forward-looking fashion only if we have a sufficient number of nuclear radiation monitoring results in the form of dose rate measurement values. But this is not so, as our preceding considerations have shown. Specifically, one must consider the following factors:

1. The value [valence] of the measurement results as such;

2. The age of the radioactive detonation products (fission products);

3. The character of prevailing terrain contamination;

4. The character of dose rate decline with the passage of time.

Classification Possibilities

1. Value [valence] of measurement results:

Tendency measurement (fallout not yet completed);

Evaluable measurement (fallout completed);

Comparable or only limited comparable measurement (only ground reconnaissance or ground and air reconnaissance).

2. Age of radioactive detonation products:

Age is known;

Age is not known;

Age is partly unknown.

3. Character of terrain contamination:

Simple radioactive trace or superposed traces of identical age;

Superposed radioactive traces essentially of differing age;

4. Character of dose rate decline with the passage of time:

Strictly follows the $t^{-1.2}$ law;

Can approximately be described by the $t^{-1.2}$ law;

Does not follow the $t^{-1.2}$ law.

If developing radioactive fallout cannot be directly matched up with a known detonation time, then the moment of that detonation can be determined relatively easily with the help of two dose rate measurements performed at a corresponding time interval at the same place. To achieve adequate accuracy, the time difference between both measurements must be all the greater, the smaller the decline in the dose rate per unit of time happens to be; that is to say, the measurement results must clearly differ from each other.

If we label the first measurement time with t_m, the second measurement time with t_n [illegible]--both of which cannot directly be matched up with the detonation time--and if we label the dose rates measured correspondingly with t_m and t_n, then, according to equation 7.35, we get the following:

$$P_m = P_0 \left(\frac{t_m}{t_0}\right)^{-1.2} \quad \text{and} \quad P_n = P_0 \left(\frac{t_n}{t_0}\right)^{-1.2}$$

if we assume that we are dealing with a fission product mixture of uniform age.

For the known ratio of dose rates between the second and first measurements, it now follows that:

$$\frac{P_n}{P_m} = \left(\frac{t_n}{t_m}\right)^{-1.2}$$

and because $t_n - \Delta t = t_m$, if Δt is used to designate the time differential between both measurements, we have

$$\frac{P_n}{P_m} = \left(\frac{t_n}{t_n - \Delta t}\right)^{-1.2}$$

From this we finally get the following by solving for t_n

$$t_n = \frac{\Delta t}{1 - \left(\frac{P_n}{P_m}\right)^{\frac{1}{1.2}}} \qquad (7.41)$$

Because practical work with this equation is too time-consuming to determine the detonation time, it is graphically illustrated in Figure 7.36 for values of Δt equal to 15 min, 30 min, 1 hr, and 2 hrs as well as for the ratio $P_n:P_m$ within the limits of 0.2-0.9. (one must always insert Δt in equation 7.41 in terms of hours.)

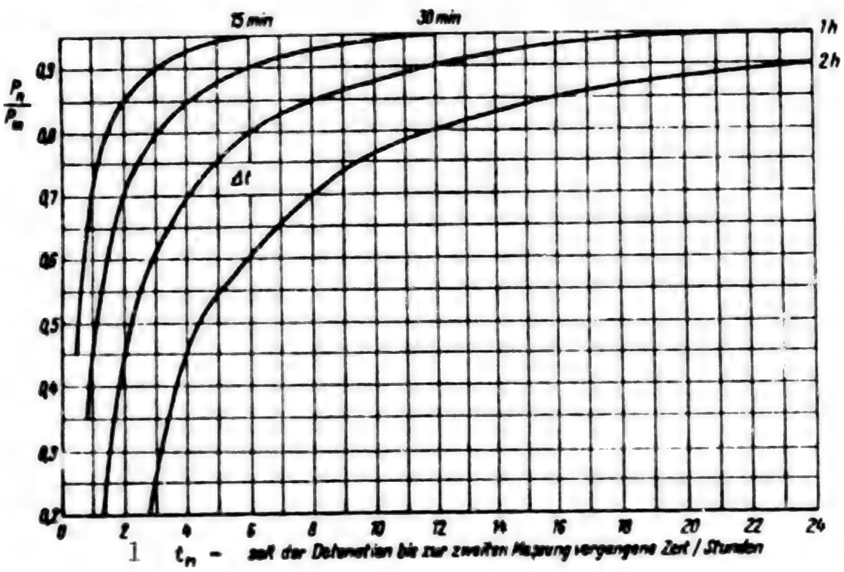


Figure 7.36. Graph for the determination of detonation time (of age of fission products). Key: 1--T_n = time elapsed since detonation up to second measurement, hours.

Example: Radioactive fallout

Radioactive fallout is detected around 1745 on 30 April in the area around a CP. Nuclear radiation monitoring at a certain measurement point around 1830 shows a dose rate of 5 R/hr^{-1} which decays only slowly and which at 2030 is still 3.5 R/hr^{-1}.

What is the age of the existing radioactive fission products; that is to say, at what time did the pertinent detonation take place?

Solution:

The following are known

$$\frac{P_n}{P_m} = \frac{3{,}5\ \mathrm{R\,h^{-1}}}{5\ \mathrm{R\,h^{-1}}} = 0{,}7; \quad \Delta t = 2\ \mathrm{h}$$

For these values we read off t_n = 8 hrs on the abscissa in Figure 7.36.

Result:

The time of the detonation, related to the second measurement, is about 8 hours back; that is to say, the detonation took place around 1230.

Note:

We get the same result also when we use the SB-1 radiation calculator (see solution method according to Problem 2).

The problems encountered in case of superposition of traces particularly depend on how great the differences are in the age of the radioactive fission products and to what extent it is possible to perform dose rate measurements for each individual radioactive fallout in order to be able to calculate the cumulative dose rates from the share of the individual detonations.

The following then applies quite generally:

$$P_i(t) = \sum_{i=1}^{n} P_{0_i} \left(\frac{t_i}{t_{0_i}}\right)^{-1,2} \tag{7.42}$$

The effort for such calculations however is rather great. They are therefore generally possible only on the basis of special programs using electronic computers. But in this case likewise we get a relatively great time requirement in order to be able to make all required initial data available to the computer. This is why in practice one must orient oneself toward other solution possibilities.

The simplest alternative in case of superposition exists when the points in time of several detonations contributing to radioactive contamination are close to each other; that is to say, if we assume:

$$\Delta H_z = H_{z_n} - H_{z_1} \ll t \qquad (7.43)$$

if we use H_z to designate the astronomic time of the particular detonation and if we use t to designate the moment of the first dose rate measurement. It is then possible to start with a uniform average detonation time:

$$\bar{H}_z = \frac{1}{n} \sum H_{z_i} \qquad (7.44)$$

and to use the $t^{-1.2}$ law with adequate accuracy both for the dose rate and for the dose calculations. The calculations can thus be performed as explained with the help of the SB-1 radiation calculator although we must expect greater inaccuracies than in the case of individual detonations.

Conditions are likewise relatively simple when there is a superposition of a "new" and an "old" trace; that is to say, if a longer period of time has elapsed since the first contamination. In this case we may assume as a rule that a clear matching of the shares of detonations out of the cumulative dose rate of gamma radiation is possible and that separate dose rate calculations and dose calculations are therefore also possible for each individual detonation.

In this connection one must however emphatically point out that neglecting the "old" trace--only because its momentary contribution to the cumulative dose rate is relatively small--cannot readily be justified. Instead, one must keep in mind that the dose rates in the "old" trace will decrease only slowly with the passage of time while this takes place very rapidly in the case of young fission products. This is why the percentage share of the gamma radiation in the "old" trace out of the cumulative dose rate can again rise rapidly.

If neither this alternative nor the first-mentioned alternative of superposition of radioactive traces applies, then it is a good idea--upon observation of major deviations in the decline of the dose rate from the $t^{-1.2}$ law or if the detonation times are not available--to perform the dose calculations with graphic methods. By the way, it seems generally necessary, in case of stationary or quasi-stationary observation points or measurement points, to work more with graphic documents and always to compare the theoretically calculated curve for dose rate decay with the one determined really through control measurements. This applies above all to the territorial area where such superpositions would not be the exception but rather the rule. In this kind of method, one can step by step extrapolate the further course of the decay curve from the dose-rate-time diagram and it is possible to determine the anticipated dose absorption during time interval t_a to t_b by means of a simple count of the "dose-area units." Naturally, one cannot then work with logarithmic scale subdivisions. This situation is illustrated schematically in Figure 7.37.

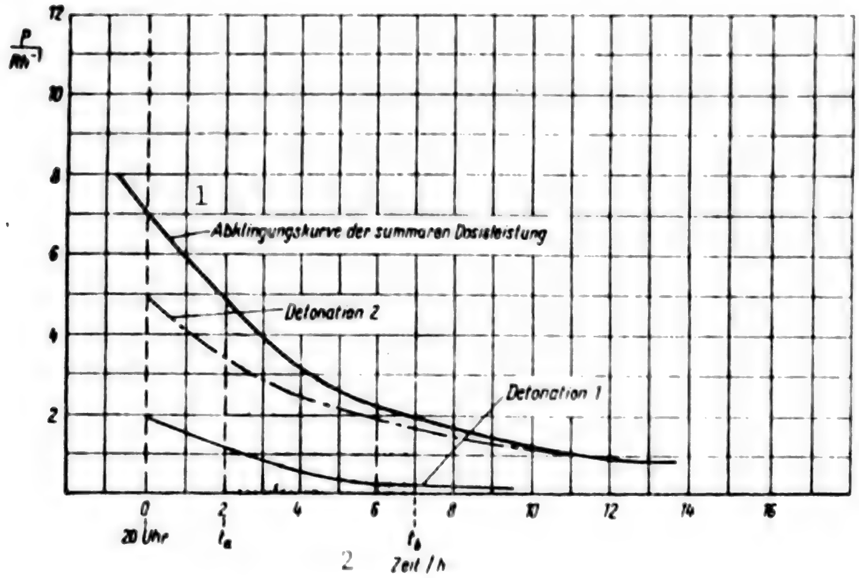


Figure 7.37. Dose-rate-time diagram in case of superposition of radioactive traces of differing age. Key: 1--Attenuation curve of cumulative dose rate; 2--Time, hr.

Explanations for Figure 7.37

In the example selected we assumed that, in the area of a measurement point, a cumulative dose rate of 7 R/hr^{-1} was measured around 2000. Further control measures produced the curve shown in the figure. Assuming that the age of the existing fission product mixture is not known or is only partly known, that is to say, assuming that exact calculations cannot be made, we get a nuclear radiation dose of about 15 R by counting out for the time span of $t_b - t_a$, other words, from 2200 until 0300. We can furthermore see that extrapolations can be performed only within narrow limits in that, in each case, the last two measurement values must be connected by an extended straight line.

In conclusion it might be observed that an incipient superposition of a radioactive trace need not necessarily be recognizable by virtue of the fact that the dose rises again at the reference point. It can make itself noticeable only through a reduction in the further decline in terms of time. Likewise, the start of radioactive fallout, following in succession in terms of time, does not tell us anything about the age of the particular fission products because both the detonation intensity and the distance from the place of detonation play a role here.[53]

7.3.3. Connection between Dose Rate and Dose in Detonation Area of Air Bursts

The terrain contamination in the detonation area of air bursts as we know is traced back to neutron-induced radioactivity. This is why in this case neither dose rate nor dose calculations are possible with the SB-1 radiation calculator.

Table 7.16. One-Hour Reference Values for Dose Rate of Gamma Radiation from Neutron-Induced Radioactivity

1 Zeit nach der Detonation	$\frac{P(t)}{P_{1h}}$	1 Zeit nach der Detonation	$\frac{P(t)}{P_{1h}}$
0	230	5 h	0,60
15 min	3,60	6 h	0,55
30 min	1,10	8 h	0,50
45 min	1,05	10 h	0,40
1 h	1	1 d	0,20
2 h	0,88	2 d	0,06
3 h	0,77	3 d	0,02
4 d	0,69		

Key: 1--Time after detonation.

The decline in the dose rate of gamma radiation from neutron-induced radioactivity with the passage of time after the nuclear weapon detonation was illustrated graphically already in Figure 7.32. The 1-hour reference values are based on equation 7.5 in Section 7.1.2. A comparison shows that the cumulative dose rate of gamma radiation from induced radioactivity decays considerably more slowly during the first four days after detonation than that of the fission products. For example, a reduction from 100 percent to 10 percent during the span of time from 1 to 7 hours after detonation in the case of fission products is contrasted by a reduction from 100 percent to only about 50 percent in the case of induced radioactivity. Table 7.16 once again summarizes these values.

Working with 1-hour reference values will now be explained with the help of two examples.

Problem:

According to Figure 7.23, the dose rate 1 hour after a low air burst of 2 kt at a distance of 500 m from ground zero is still 0.5 R/hr^{-1}. What dose rate can we expect at the same point 4 hours after detonation?

Solution:

From Table 7.16 we get $P_{4h} = P_{1h} \cdot 0{,}69 = 0{,}5 \text{ R h}^{-1} \cdot 0{,}69 \approx 0{,}35 \text{ R h}^{-1}$. If we have a dose rate not pertaining to 1 hour after detonation, then one must in each case figure back via the 1-hour reference value.

Problem:

A dose rate of 10 R/hr^{-1} is measured 10 hours after a low air burst 200 m from ground zero. What dose rate do we expect at the same point one day after detonation?

Solution:

From Table 7.16 we take:

$$P_{10h} = P_{1h} \cdot 0{,}40 \quad \text{and} \quad P_{1d} = P_{1h} \cdot 0{,}20$$

From this it follows that:

$$P_{1d} = P_{10h} \cdot \frac{0{,}20}{0{,}40} = 10\,\mathrm{R\,h^{-1}} \cdot 0{,}5 = 5\,\mathrm{R\,h^{-1}}$$

The computation of the probable dose absorption by way of prediction in the course of operations in the detonation areas of air bursts is a problem inasmuch as the dose rates change very much with the distance from ground zero. This is why it is difficult under these conditions exactly to define the particular average dose rate.

Assuming that the radioactively contaminated detonation areas cover only a small surface and that the dose rates in them decline relatively slowly during the first hours after detonation, one can calculate the anticipated radiation exposure during a stay in the area according to the following relation:

$$D = P_{max} \cdot t \cdot f_s \quad \mathrm{R} \tag{7.45}$$

and we get the following when crossing the detonation area:

$$D = 0{,}5 \cdot P_{max} \cdot t \cdot f_s \quad \mathrm{R} \tag{7.46}$$

P_{max}--Maximum dose rate in area of stay or in direction of movement at start of stay or during movement, R/hr^{-1}.

t--Duration of stay or through-movement, hrs

f_s--Attenuation factor of particular combat vehicle (here we use the attenuation [protection] factors for fission products).

The nuclear radiation doses calculated in this way as a rule will be somewhat higher than the real radiation exposure, especially during longer times spent in the area. Nevertheless, because of the uncertain initial data it makes little sense to work with detailed computation methods or perhaps even to try to develop special computation aids for this purpose.

Review Questions

7.27. For nuclear radiation calculations under field conditions, radioactive contamination normally is traced back to fission products. What is the single exception to this?

7.28. Explain the concept of the dose constant of gamma radiation.

7.29. According to what laws does the dose rate of gamma radiation from a point-shaped source decrease with distance from the source?

7.30. What conclusions can be arrived at regarding the conduct of nuclear radiation monitoring?

7.31. What empirical connection is there between area radioactivity and dose rate of gamma radiation at a height of 1 m in the radioactive trace?

7.32. In the detonation area of a ground burst and an air burst, 10 R/hr^{-1} were recorded in each case 1 hour after the detonation. Why should we expect different radiation exposures in both cases even though we spend the same period of time in the area?

7.33. What connection is there between the dose rate and the dose of gamma radiation from fission products? Which three basic computation alternatives are possible and when are they best used?

7.34. What do we mean by the term of "integral nuclear radiation dose" and what is its significance in connection with predicting fallout by dose zones?

7.35. Explain the makeup of the SB-1 radiation calculator. What kind of calculations can be performed with it?

7.36. Mention the most important rules on dose rate and dose from fission products. Demonstrate their use with the help of examples.

7.37. Why must we have additional initial data, along with the dose rates, in describing an existing terrain contamination situation?

7.38. How can we determine the age of a fission product mixture, that is to say, the moment of the pertinent detonation, by means of dose rate measurements?

7.39. What problems are connected with the superposition of radioactive traces?

7.40. What are the determinations concerning dose rate and dose calculations for the detonation areas of air bursts?

7.41. What conclusions did you draw from what we have said so far about the possible accuracy of dose rate and dose calculations under field conditions? What is your estimate of the ratio between analytical evaluation--that is to say, theoretical computations--and nuclear radiation monitoring?

7.4. Measures to Protect Units during Operations in Large Contaminated Zones

7.4.1. Nuclear Radiation Situation as Semistrategic-Tactical Factor

As a result of the massive use of nuclear weapons in the form of ground and underground bursts in certain directions or areas--whereby massive use can be implemented through individual nuclear weapons of great detonation intensity or a larger number of nuclear weapons of smaller detonation intensity--vast areas are so heavily contaminated that terrain contamination has an effect far beyond the tactical framework and assumes semistrategic significance. This realization means that, approximately since the year 1960, the concept of the nuclear radiation situation has become a firm component in the decision-making process.

The nuclear radiation situation characterizes all conditions which result for unit combat operations from terrain contamination caused by nuclear weapon employment and the attendant effects of residual nuclear radiation.

The particular nuclear radiation situation is characterized primarily by the level of the nuclear radiation dose to which the troops were exposed during a certain span of time and/or the anticipated dose absorption.

Here are the most important elements of the nuclear radiation situation:

The size, shape, and location of the contaminated zones;

The level of the maximum and average dose rates present in these zones at a certain time in terms of semistrategic operations;

The radiation exposure of the troops to be expected in the course of combat operations, considering past dose absorption; and

The prevailing or probable degree of radioactive contamination of personnel, combat vehicles, technical combat equipment, supply items, etc.

In addition, such questions as the anticipated start and duration of radioactive fallout at the various distances and the reduction of the dose rates with the passage of time play a role.

The nuclear radiation situation restricts unit operations in terms of time and space. Here, one of its most important characteristics is its constant change. This is why the evaluation of the nuclear radiation situation and the drafting of the corresponding conclusions by the staffs is an uninterrupted process which is based not only on the foundation of analytical evaluation[52] but also on nuclear radiation monitoring and dosimetry.

The nuclear radiation situation is not an independent complex but is rather always a component of the general situation. Only from this viewpoint is its real evaluation possible and only from this viewpoint can its significance and influence on combat operations be estimated accurately and in longer-range terms.

Initial or information data are required for an estimate of the nuclear radiation situation. They include the following:

Data on the location and operations of friendly units and enemy units (operational areas, type of combat operations, protection status, past radiation exposure, etc.);

Nuclear weapon detonometry monitoring results;

Data on the high-altitude and surface weather situation and its further development; as well as

Measurement results from nuclear radiation monitoring and dosimetry.

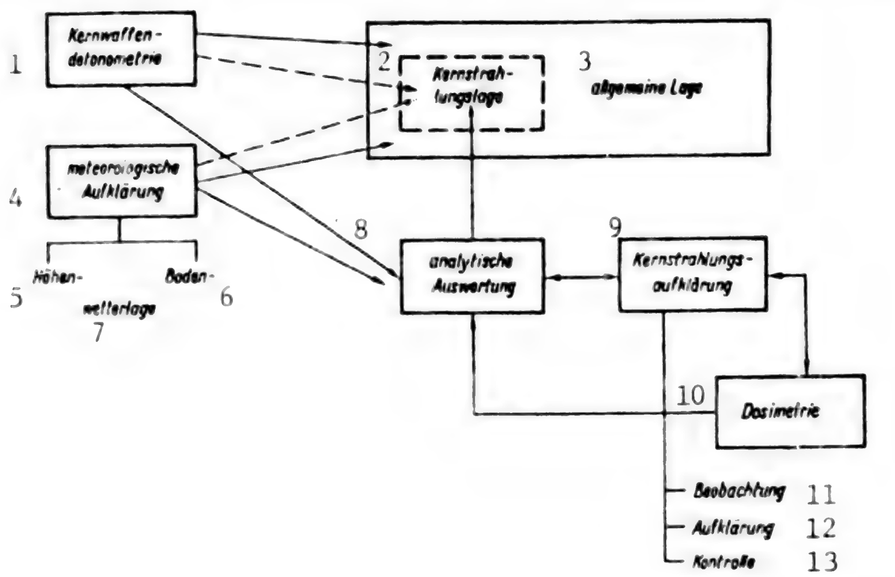


Figure 7.38. Diagram illustrating prerequisites for preparation of nuclear radiation situation. Key: 1--Nuclear weapon detonometry; 2--Nuclear radiation situation; 3--General situation; 4--Weather observation; 5--High-altitude; 6--Surface; 7--Weather situation; 8--Analysis; 9--Nuclear radiation monitoring; 10--Dosimetry; 11--Observation; 12--Reconnaissance; 13--Control.

In the process of preparing a nuclear radiation situation estimate, the following questions must be answered in detail:

In what directions is radioactive fallout spreading, when are certain sectors reached, and at what time can one consider trace formation as having been completed?

On what surface area can we expect the appearance of radioactive fallout with what degree of probability,and what dose rates or integral nuclear radiation doses can we expect at the particular distances in the trace?

What is the influence of radiation exposure and the radioactive contamination of the troops on the accomplishment of the combat mission?

By means of what protective measures can the effect of the existing nuclear radiation situation on further unit operations be diminished?

What tasks arise in the complex measures to eliminate the consequences regarding nuclear radiation reconnaissance, dosimetry, and special treatment?

We must start with two basic principles in order to be able to draw correct conclusions in semistrategic-tactical respects from the evaluation of the nuclear radiation situation:

1. In case of combat operations in contaminated zones, the radiation exposure of the troops must be kept as small as possible in order to reduce casualties due to radiation sickness to a minimum.

2. There are basically only three possibilities for reducing the radiation exposure of the troops. They consist in carrying out maneuvers for the purpose of going around heavily contaminated areas or restricting the time spent in them (shift system), using the radiation-attenuating effect of combat vehicles and shelters of all kind, and carrying out measures to prevent the incorporation of radioactive substances.

The knowledge of the initial data on enemy nuclear strikes and the high-altitude weather situation makes it possible with a certain degree of probability to estimate the directions and areas that are most threatened in terms of radioactive contamination in conjunction with the overall situation. Here an important task is to warn directly threatened units at the right time and to shift them around as a function of the anticipated maximum dose rates where possible even before the start of radioactive fallout if no adequate protection possibilities are present. In case of massive ground or underground bursts, the possibilities for such maneuvers however may be severely restricted.

On the basis of the analysis and results of nuclear radiation reconnaissance, the staffs must draw conclusions as to which areas or sectors in the radioactively contaminated zones are so heavily contaminated or are being so heavily contaminated that the troops will be wiped out or suffer heavy losses even in case of a limited stay in those areas, which sectors during which intervals of time in fact are no longer passable or under which conditions they can be negotiated.

Concerning the radiation exposure of the troops, the type and duration of stay or crossing are decisive in addition to the level of the dose rates. Because, as we know, the dose rates during the first few hours after nuclear weapon detonations decrease particularly rapidly, it follows that contaminated zones should be crossed as late as possible, from this viewpoint.

The best prerequisites for successful operations even under the conditions of a complicated nuclear radiation situation are available to armored forces because they can cross sectors with high dose rates quickly and furthermore the tanks and APC's offer relatively high protection factors against residual nuclear radiation.

In case of combat actions and major operations in vast contaminated zones, maneuver-like actions by the units assume increased significance.

Severe terrain contamination after massive nuclear strikes can heavily restrict the mobility of troops on the battlefield and can make it difficult to accomplish the assigned mission. Going around heavily contaminated sectors or areas however is not in every case possible and practical under these conditions. This is why special attention must be devoted particularly to the job of crossing these areas. Areas with high dose rates must be crossed in the best sectors via the shortest route with maximum speed. The term "favorable sector" here must be understood not only with a view to the dose rate but also the passability of the terrain, the condition of the road and trail network, the element of surprise regarding the enemy, etc.

It is quite understandable that maneuvers in case of a complicated nuclear radiation situation are decisively influenced by the extent to which we get a sufficiently informative overall view of the particular operational area. This again raises certain requirements for unit leadership and cooperation.

It is likewise not always possible and practical immediately to leave contaminated areas or to shift troops out of contaminated areas. This in particular is not the case when the troops are surprised by radioactive contamination and when they have adequate protection. This is quite apart from the fact that the accomplishment of various missions may force the units to hold a heavily contaminated area for a longer period of time.

The purpose of quickly shifting units out of heavily contaminated areas is to reduce their radiation exposure. The latter in this case likewise consists of the partial dose which took effect during the time of stay in covered position, shelters, buildings, and installations, and the other partial dose which is absorbed during the time the troops are led out of the contaminated area. There is an optimum in each situation for the moment to be selected for moving the troops out. That moment must come all the more late, the smaller the radiation-attenuating effect of combat vehicles happens to be in relation to the shelter facilities.

It is obvious that in cases where march movement roads have been insufficiently reconnoitered, where the distances leading to uncontaminated or only slightly contaminated areas are great or where the dose rates are very high, the radiation exposures in case of hasty and poorly organized evacuation can be considerably above those that would appear in case of maximum exploitation of existing shelter facilities. These conditions among other things can be of significance for some of the rear-area installations.

It is undoubtedly true that, in preparing a nuclear radiation situation estimate, those questions will always be at the focus which have to do with unit radiation exposure. But that by far does not exhaust the concept of the nuclear radiation situation. One must instead also consider those factors which result from the specific combat and working conditions in contaminated zones. This includes the radioactive contamination of personnel and the various objects by radioactive dust which normally forces the troops to put

on protective gear, which calls for special action, which imposes a series of restrictions on fightingmen, and which therefore forces them to face extraordinarily severe physical and psychological stresses. A complicated nuclear radiation situation demands circumspect and resolute action on the part of commanders and staffs as well as clear and unambiguous orders and instructions also in situations that are sometimes not at all clear.

The radioactive contamination of large areas for example also severely encumbers the work of rear-area support units, particularly regarding ration supply and water supply. The activity of medical facilities can be considerably hindered. Use of local reserves can be restricted or can be rendered impossible. Open watering places can be rendered useless for a longer period of time, rivers can carry heavily radioactive water over long distances even outside contaminated zones, and so forth and so on.

These few examples clearly show that the nuclear radiation situation must always be evaluated in a comprehensive fashion and in terms of its concrete effects.

The semistrategic-tactical influence of the nuclear radiation situation on unit operations must be taken into consideration in the determination of the direction of the main strike or the main direction of thrust or the direction of the main effort, the semistrategic buildup or the order of battle of the various units and the organization and execution of troop movements and maneuvers, especially in conjunction with the introduction of the second echelons and reserves.

In determining the main thrust direction, one must keep in mind that the terrain permits broad deployment possibilities for maneuvers to go around heavily contaminated areas and the avoidance of successive crossings of contaminated zones. This above all is very important for the second echelons and reserves so that their fighting strength will not be weakened prematurely. In this context it is necessary to demand that the troop be given a sufficiently wide action sector. The width of this action sector must facilitate the leading of the attack in terms of certain directions and must guarantee the units freedom to maneuver. Nevertheless, the case might arise where going around contaminated zones will force individual major or minor units temporarily to side-step into the operation areas of their neighbors. To make sure that these units will not interfere with each other in such cases and to prevent an impermissible concentration of personnel and equipment, these alternatives must be weighed in a forward-looking manner under the conditions of a complicated nuclear radiation situation.

The massive use of nuclear weapons can cause the general situation and consequently also the balance of forces to change quickly and fundamentally. Under these conditions, strong second echelons and reserves assume particularly great significance. This is true not only with respect to the relief of units directly hit by enemy nuclear strikes but also with respect to broadening the success in depth, when certain elements of the main force are severely restricted or hindered in terms of their freedom of movement in areas with high dose rates. The presence of strong and mobile reserves in such cases

--even in conjunction with a complicated nuclear radiation situation--makes it possible to preserve a fast attack tempo, to push the attack from new directions, to insert new units at the right time and to go around or cross heavily contaminated areas efficiently. Under all these conditions, backup support for rapid and exact maneuvers and troop movements also over great distances assumes increased significance. In estimating this influence exerted by the nuclear radiation situation one must particularly in semistrategic respects realize completely clearly that bypassing will not always be readily possible on the basis of the possible large area covered by a contaminated zone. On top of that we have the fact that bypassing as a rule leads to a change in the assigned mission or to a considerable loss of time and that the element of surprise may be lost. This is why the decision as to bypassing or crossing, in addition to the radiation exposure estimate, will always depend on the general mission and the specific situation.

In this connection it is necessary when giving the assignment and when building up the semistrategic deployment pattern or the combat formation, to consider the past and anticipated radiation exposure of major and minor units and to prevent units which have already been exposed to heavy radiation doses from once again being employed in the most heavily contamined areas or in the corresponding directions.

As a result of ground and underground detonations in particularly important sectors or areas, such as traffic junctions, difficult terrain sectors, and river crossing points, the terrain contamination can so severely restrict the freedom of movement of the units that one can in a certain sense speak of a channelling effect. Because in such situations not only the forward movement is heavily slowed down but because the danger of a concentration of forces is also great, it is necessary when planning combat operations or strategic operations to make full use of the entire available area for troop movements and maneuvers. This includes not only the full utilization of the highway and road net or the realistic estimate of terrain passability but also the evaluation of the high-altitude weather situations regarding the anticipated main directions of radioactive fallout in order to avoid troop movements or concentrations "along the axes of the radioactive traces." In this connection it is also possible to consider this problem complex during the planning for the shift of command facilities, rear-area installations, etc., to a certain extent.

The nuclear radiation situation has an effect on the operations of the other services that is similar to the effect on ground forces operations. In the case of naval forces and air defense forces, whose combat command procedures are tied to certain bases (ports, airfields, positions, etc.) to a much greater extent than the ground forces, much attention must be devoted especially to the questions of protracted stay in heavily contaminated zones. Here, stepped-up Engineer improvement of shelter facilities as well as the problem complex of shift work will play an essential role. In the case of the air forces it will not be enough to estimate only terrain contamination but one must also estimate the contamination of the air space. In this connection it might be noted in conclusion that the terms "direction of propagation of the radioactive detonation cloud" and "direction of propagation of the radioactive trace" describe different situations.

7.4.2. Measures to Reduce Radiation Exposure and Incorporation Danger

7.4.2.1. Protection against External Radiation

The causes and consequences of terrain contamination covered so far clearly show that the detonation products located in contaminated terrain emit gamma, beta, and alpha radiation. From the viewpoint of external radiation, gamma radiation is most dangerous because of its great penetration capacity and it is therefore primarily used as basis for all radiation protection computations. In a few cases it is necessary in addition to consider the effect of beta radiation.

Apart from the fact that the quantum energy of gamma radiation from detonation products (fission products) is considerably smaller than that of the gamma component of instantaneous nuclear radiation and that the effects of alpha and beta radiation during combat operations in contaminated zones must be added on top of this, we can say that the peculiarities in the effects of residual nuclear radiation above all consist in the fact that the time span of dose absorption can extend to hours, days, and weeks, and that, furthermore, there is a direct danger of incorporation of radioactive substances.

As in the case of instantaneous nuclear radiation, so, in the case of residual nuclear radiation, the nuclear radiation dose absorbed is of decisive significance in terms of the magnitude of the anticipated radiation damage. But here the time factor likewise plays an essential role. The longer the span of time over which a certain dose absorption is distributed, the less will be the anticipated somatic damage. It has already been established that, in case of momentary radiation exposure, the lethal dose (LD_{100}) is 600 R. In case of uniform distribution over the span of a month, the lethal dose on the other hand will be 1,500 R.

Because the general biological effects were illustrated already in conjunction with coverage of instantaneous nuclear radiation in Section 5.3.3.2 also for residual nuclear radiation, there is no need here once again to go into these questions.

Table 7.17 gives the maximum permissible nuclear radiation doses (MzD) for external radiation as a function of the duration of combat operations in contaminated zones. These values must be so interpreted that, if they are complied with, we need not expect any immediate casualties due to radiation sickness. But it would be wrong to think that this involves "undangerous" nuclear radiation doses because that directly conflicts with the requirement for accomplishing the combat mission with the least possible radiation exposure and because this is also in no way in line with the biological situation.

Table 7.17. Maximum Permissible Nuclear Radiation Doses (MzD) for Combat Conditions

Radiation Effect Conditions	MzD
One time absorption over 4 days	Up to 50 R
Repeated absorption over	
10 days	to 100 R
3 months	to 200 R
1 year	to 300 R

Note: The maximum permissible nuclear radiation doses defined for longer periods of time include the fact that the values specified for shorter time intervals must not be exceeded.

Preserving the combat strength of the units means that all available possibilities to provide protection against outside radiation must be utilized to the maximum degree in every situation. The goal is not simply not to exceed the specified maximum doses but rather as much as possible to remain below the maximum permissible nuclear radiation doses.

Both technical and semistrategic-tactical measures serve to attain this goal; together, they are called nuclear radiation protection measures under field conditions although they naturally, by virtue of the essence, are measures for the protection of units against mass annihilation weapons and although a clear dividing line with respect to other complexes of protection is not always possible.

The technical possibilities of radiation protection under field conditions (nuclear radiation monitoring, dosimetry, decontamination, creation and utilization of shelters, etc.) as a rule result directly from the specific situation. They are more or less of a universal nature and therefore they are not specific for a certain type of combat operation or a certain command echelon. This is why these questions can be decided relatively quickly and independently by the commanders and staffs themselves.[55]

The situation is different in the case of semistrategic-tactical measures. They essentially encompass various types of maneuvers with relation to radioactively contaminated zones and they always presuppose the accomplishment of the combat mission. Considering the significance of the nuclear radiation situation taken up in the preceding chapter as a semistrategic-tactical factor, we would now like to examine some pertinent problems in greater detail.

The radioactively contaminated zones are further classified regarding their degree of radioactive contamination or the dose rate level or the integral nuclear radiation doses and the resultant effect on unit combat operations.[56]

In general, we distinguish the following:

1. Zones of Moderate Contamination

In these zones, personnel outside shelter as a rule will absorb a dose above the maximum permissible values only if their stay extends over many hours and if there is no possibility of temporarily using combat vehicles or simple shelters. In the case of crews of armored combat vehicles, we cannot expect a loss of combat capacity even if they stay in the area for a longer period of time.

2. Zones of Strong Contamination

These zones completely restrict the stay of troops outside shelter and require a strictly limited time of stay also for armored forces. A longer stay is possible only if special shelter facilities (shelters, basements) are made available or are present. One must expect casualties here.

3. Zones of Dangerous Contamination

These zones make even short operations outside shelters impossible without leading to extremely high radiation exposures. Even the attenuating effects of tanks and APC's are not enough for remaining in the area without danger--even if the units stay in the area only for a short time.

Developed defense positions can of course prevent heavy losses but active operations are made very difficult.

The use of one or the other type of maneuver as radiation protection measure under the particular conditions of the situation in each case will depend on the combat mission, enemy action, the location, size, and character of the radioactively contaminated zones, the past radiation exposure of the units, and the geographic and weather conditions.

Specifically, a reduction in the radiation exposure of the units can be achieved by means of the following:

Crossing contaminated zones in favorable directions,

Going around zones of strong or dangerous contamination,

Waiting for dose rates to decline,

Air transport and

Combination of several of the maneuvers mentioned here.

Regardless of the type of maneuver, the cumulative radiation exposure of military personnel always consists of three component doses; that is to say, the one which takes effect in the original area, the one that takes effect during movement, and the one which takes effect in the new area.

In this connection one must of course keep in mind that, under the conditions of large contaminated surface areas, a maneuver can be employed in order to shift the troops:

From one uncontaminated area to another one,

From a contaminated area to an uncontaminated area and

From a heavily contaminated to a less heavily contaminated area,

That is to say, that several partial doses can also be equal to zero.

Just how fast a contaminated area must be left or crossed or, in other words, the interval of time during which combat capacity is lost or correspondingly impaired, among other things will be decisively influenced by the state of protection of units in the contaminated area itself and during their movement.

Every combat vehicle and all field fortifications, especially shelters, as well as buildings and installations of all kinds, will attenuate residual nuclear radiation and therefore offer protection, although in different degrees.

Looking at it this way, the determination of the right time for performing one or the other maneuver is a mathematical optimization problem although, in saying this, we do not want to oversimplify the tremendous complexity of combat operations by units in contaminated zones.

In order fully to understand this problem complex, it is necessary to compare the protection factors of the various combat vehicles and installations.

Table 7.18 clearly shows that the values of the attenuation [protection] factors of shelter facilities in general are by one order of magnitude below those of the combat vehicles; that is to say, that the state of protection of units in terrain or in towns, which were improved by the Engineers, will be considerably higher than in combat vehicles.

The protection factors of combat vehicles as such differ considerably from each other so that, other things being equal, the radiation exposures for the crews of motor vehicles, APC's or tanks, will show a ratio of 10:5:2. If one furthermore considers the differing maneuverability and mobility of these combat vehicles, then this ratio will be even more differentiated. It follows from this that armored units have considerably better prerequisites for combat operations in contaminated zones than motorized rifle units and that the latter, in turn, for example, are better off than rear-echelon logistic units, if they are equipped only with motor vehicles.

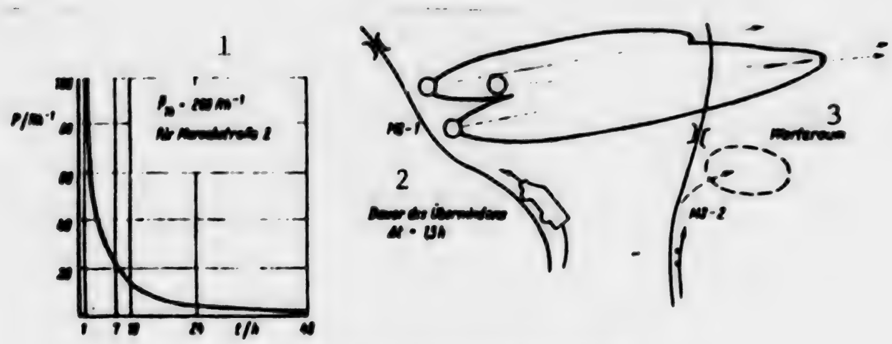
Table 7.18. Mean Values of Residual Nuclear Radiation Protection Factors for Various Objects

Type of Object	Protection factor
Foxholes	0.1
Trenches, open, not decontaminated	0.3--0.5
Trenches, open, decontaminated	0.05
Trenches, covered, not decontaminated	0.1
Trenches, covered, decontaminated	0.04
Shelters, light-weight type	0.03
Shelters with dirt cover of more than 1 m	<0.001
Wooden houses	0.3
Stone houses, one story	0.1
Stone houses, two stories	0.05
Stone houses, three stories	0.03
Stone houses, more than three stories	<0.01
Motor vehicles	0.5
APC's	0.25
Tanks	0.1
Railroad cars	0.3
Aircraft	0.5

To make this presentation shorter, we will also briefly explain some additional problems with the help of examples which the reader can accordingly vary or interpret if he works along with us actively. The calculation methods generally are outlined only briefly. In this connection reference is made to the mathematical setup in Section 7.3.

Example 1

Crossing contaminated zones and waiting for the dose rates to decline (Figure 7.39).



4 Tabelle der Strahlungsbelastung (gerundete Werte)

Variante 1 5 Überwinden der „neuen" Spur				Variante 2 6 Überwinden der „alten" Spur			
7 beim Überwinden nach	8 Dosisaufnahme / R mit Pz	9 SPW	Kfz	7 beim Überwinden nach	8 Dosisaufnahme / R mit Pz	9 SPW	Kfz
1h	15	30	75	1d	0,8	1,5	3
3h	3	6	15	1,5d	0,05	1	2,5
10h	1	3	5	2d	0,3	0,7	1,5

Figure 7.39. Key: 1--For march route 2; 2--Duration of crossing; 3--Standby area; 4--Radiation exposure table (figures rounded); 5--Variant 1, crossing the "new" trace; 6--Variant 2, crossing the "old" trace; 7--In case of crossing after; 8--Dose exposure/R; 9--With; Pz--Tank; SPW--APC; Kfz--Motor vehicle.

(In the example selected, all time indications refer to the average timing of the three nuclear weapon detonations. As the calculation value for march route 2 we assumed a dose rate of P = 200 R/hr^{-1} when t = 1 hr after detonation.)

The table clearly shows that, when getting through a newly contaminated zone, in other words, during the first hours after the formation of the trace, even a brief delay of the start of the crossing movement will lead to a considerable reduction in the radiation exposure of the troops. On the other hand, in the case of old traces (variant 2), the exact moment of crossing the area is of less interest.

The numerical figures calculated furthermore clearly show that the state of protection plays a great role during the crossing move. One must however not draw any hasty conclusions from this fact. First of all one must keep in mind that we may have mixed convoys in a whole series of cases or that we might have convoy parts in a particular march movement order with different protection factors. Besides, while crossing the area, the unit may be forced to stay there longer also in heavily or dangerously contaminated zones due to enemy action or due to demolition and the blocking of march routes, due to fires, floods, etc. In this case the radiation exposure (variant 1) rises rapidly and can even lead to the loss of combat capacity. In our example, an additional stay of 1 hour will increase the dose absorption during the crossing time interval from 1 to 10 hours by 10-130 R.

Example 2

On leaving or staying in a contaminated area (Figure 7.40)

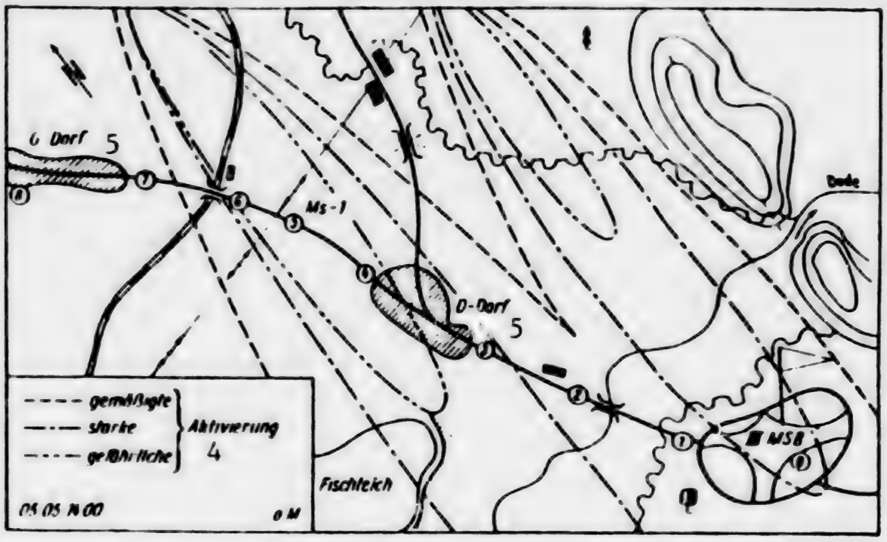


Figure 7.40a Key: 1--Moderate; 2--Heavy; 3--Dangerous; 4--Contamination; 5--Village; 6--Fish pond; MSB--Motorized Rifle Battalion.

1

Meßpunkt-Nr	0	1	2	3	4	5	6	7	8
P/Rh^{-1}	20	10	15	25	65	75	40	5	1

2

Auskunftsangaben

Beginn des radioaktiven Niederschlags im Ausgangsraum des III. MSB: 13.00 Uhr,
Länge der Marschstrecke Ausgangsraum – Westausgang G-Dorf: 30 km,
Mittlere Marschgeschwindigkeit: 15 km h^{-1},
Mittlere Dosisleistung der Marschstrecke P_{1m} = 25 Rh^{-1}, des Ausgangsraumes P_{1a} = 20 Rh^{-1};
Berechnungsgrundlage für den Marsch: SPW mit f_s = 0,25 bzw. KFz mit f_s = 0,5, für den Ausgangsraum: abgedeckte Gräben mit f_s = 0,1

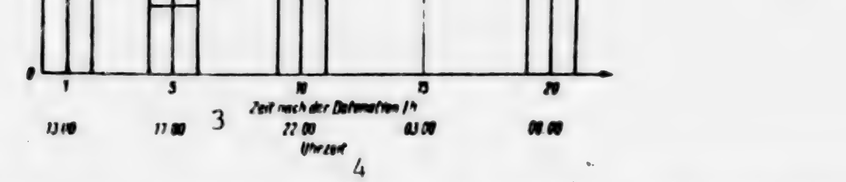


Figure 7.40b. Key: 1--Measurement point number; 2--Informational data: start of radioactive fallout in jump-off area of 3 MSB: 1300; length of march route

[Key continued on following page]

[Key to Figure 7.40b continued] from jump off area to western exit of G-village 30 km; average march movement speed: 15 km/hr^{-1}; average dose rate on march route $\bar{P}_{zh}$ = 25 R/hr^{-1}, of jumpoff area, $\bar{P}_{zh}$ = 20 R/hr^{-1}; calculation base for mach movement: APC with f_s = 0.25 or motor vehicle with f_s = 0.5, for jumpoff area: covered trenches with f_s = 0.1; 3--Time after detonation, hrs; 4--Clock time; 5--Dose absorbed during march movement; 6--Dose absorbed during break; Kfz--Motor vehicle; SPW--APC.

In the example calculated here, where the required informational data are already given, we can clearly see that the best time interval for moving the 3rd MSB out of the jumpoff area on march route 1 toward G-village is between 1700 and 2200, that is to say 5-10 hours after the detonations. The dose rate level, other things being equal, in fact does not have any influence on the position of this time interval, apart from extreme differences in the average dose rates in the jumpoff area and on the march route. The decisive thing instead is primarily the ratio between the protection factors of the shelters in the jumpoff area and those of the combat vehicles. The better the jumpoff area has been developed and improved by the Engineers, the later should we leave it in order to minimize the troops' radiation exposure. Such assignments of course cannot be exactly figured out completely as a rule under field conditions but they can be rapidly accomplished at least by means of an uncomplicated comparison calculation.

Example 3

Determination of average dose rate for march routes (Figure 7.41).

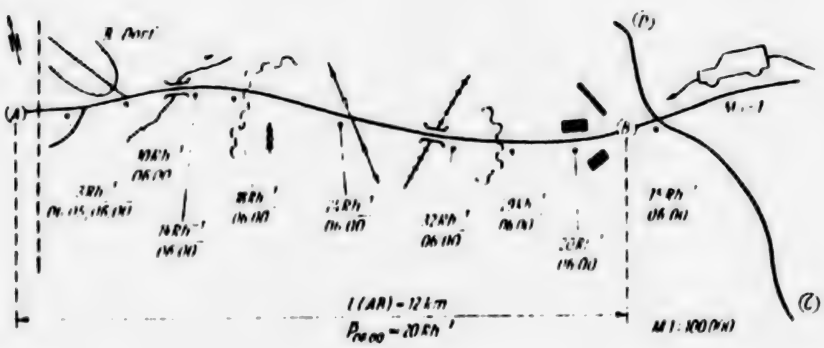


Figure 7.41.

Dose calculations for unit operations in contaminated zones frequently as the first step require the conversion of the measured dose rates to a uniform semistrategic reference time while the second step involves the determination of an average dose rate for a march route, a direction, or an area. Such calculations must always be connected with an evaluation of the information content of the initial magnitudes in order from the very beginning to prevent any kind of playing with numbers. The computation method to be selected must in particular take into account the density of measurement points and the relative differences in the dose rates. Specifically, the calculations can be performed according to three methods.

Assuming that we only have very sketchy reconnaissance reports, although the maximum dose rate of a sector of a radioactive trace to be crossed may be known, the following empirical relation applies:

$$D = \frac{0{,}25 \cdot P_{max} \cdot l \cdot f_0}{v_M} \quad R \qquad (7.47)$$

l--Length of contaminated sector, km
f_0--Protection factor of combat vehicle (Table 7.18)
v_M--March movement speed, km/hr^{-1}

If we have a relatively uniform measurement point density and if the dose rates do not differ too much from each other with the distance, then we can use the following formula:

$$D = \frac{\bar{P} \cdot l \cdot f_0}{v_M} \quad R \qquad (7.48)$$

whereby we get the average dose rate $\bar{P}$ from the following:

$$\bar{P} = \frac{P_1 + P_2 + \cdots + P_n}{n}$$

If the fission products are only a few hours old and if the march movement lasts somewhat longer, then formula 7.48 will give us dose values which will be too high because it does not allow for the decay of the dose rate. In these cases it is a better idea to solve the problem with the SB-1 radiation calculator, using the average dose rate $\bar{P}$ at the start of the march movement.

One last method of dose calculation for march routes finally consists in calculating the total dose from the partial doses for individual sectors of a contaminated march route in case of differing density of measurement points and widely differing dose rates. This method is above all suitable when we have $t_a \gg t_b - t_a$; that is to say, when a longer interval of time has already elapsed since the formation of the trace. It is however very time-consuming and therefore not universally usable.

This kind of computation has the following form:

$$D = f_0 \sum \frac{P_{x\,km} + P_{y\,km}}{2} \Delta t \quad R \qquad (7.49)$$

that is to say, the dose calculation for the particular segment of the march route is based on the average dose rate of this segment and the time it takes to pass through this segment. The danger of external radiation is confined not only to the time interval involved in the immediate stay in contaminated terrain itself but also continues to exist beyond the radioactive contamination of combat vehicles and combat equipment after the contaminated areas have been left. Just how high the nuclear radiation doses are, to which vehicle and gun crew members will be exposed, depends on very many factors.

In case of dry ground (dust formation), the entire combat vehicle is contaminated more or less uniformly heavily whereas in case of a damp soil, contamination in fact is confined to those parts which are directly in contact with the contaminated soil. Here we get such a concentration of radioactive dirt in the suspension and along the bottom of the hull especially in the case of tracked vehicles that the resultant surface radioactivity can therefore by a multiple exceed that of the surrounding terrain. Contamination of course decreases during a subsequent march through uncontaminated terrain. Only the natural decay of fission products is responsible for this reduction in case of dry weather; in case of damp soil, the exchange of the adhering dirt masses also has a certain effect. In general we can therefore figure that the additional radiation exposure to the personnel--caused by contaminated combat vehicles--can be 10-30 percent of the nuclear radiation dose in the terrain. This is why it is not correct to explain the need for rapid decontamination only in the light of the existing danger of incorporation.

It was pointed out earlier that it is necessary in some cases, in connection with outside radiation, also to consider the effect of beta radiation. If the radioactive detonation products are found only in the terrain or on the surface of combat vehicles, etc., then the practical radius of the contaminated surface area, from which beta radiation is radiated, will be about 3-5 m. If we furthermore start with the characteristic of fission product beta radiation given in Section 7.1, then it follows that, if the troops are stationed out in the open, the resultant dose will not exceed 5-10 percent of the corresponding gamma radiation dose and that it can therefore be neglected.[57] Beta radiation is of no concern anyway when the troops are in shelters (see Section 7.1.4.2).

Another viewpoint emerges in the presence of contact radiation, that is to say, when beta-active substances get directly on the skin and especially the mucosae. In this case, all beta particles with an energy of E_β/60 to 70 keV --which penetrate the outermost skin layer (surface mass about 7 mg/cm^{-2})-- will contribute to a corresponding tissue dose. The magnitude of this dose decreases continually in case of direct contact of radioactive substances with the body surface.

Petrov[58] points out that, if the radioactive detonation products remain on the skin surface for a longer period of time, the developing high surface doses can cause serious injuries that have the character of beta burns. Such beta burns were observed for example among the inhabitants of the Marshall Islands as a result of the American nuclear weapon experiments conducted in March 1954. In case of a whole-body gamma radiation dose of about 175 rad (175 R), caused by external radiation, in case of unprotected body parts, resulting from beta radiation and soft gamma radiation, there were skin doses on the order of magnitude of 2,000 rad on the level of the heels, 600 rad on the level of the thigh, and 300 rad on the level of the head. On this basis, Petrov arrives at the conclusion that, under the conditions of heavily contaminated areas, the contact doses of beta radiation for unprotected skin can be more than 10 times higher than the whole-body doses.

This points up the great significance of wearing protective gear during operations in contaminated zones.

Table 7.19. Permissible Radioactive Contamination of Surfaces and Objects

	3 Bezeichnung	4 zulässige Aktivierung Beta-Zerfalle auf 1 cm² und min		mR/h	
		5 alt¹)	6 neu¹)	5 alt	6 neu²)
7	Körperoberfläche des Menschen	0,05	1,1	0,75	15
8	Handflächen	0,1	2,2	0,2	4,5
9	Körperoberfläche von Tieren	0,2	2,2	3,0	30
10	Schutzmaskenhaube	0,5	1,1	1,0	10
11	Unterbekleidung	0,05	1,1	0,75	15
12	Oberbekleidung, Ausrüstung, Schuhwerk und persönliche Schutzausrüstung	0,2	2,2	3,0	30
13	Handfeuerwaffen	0,5	2,2	3,0	15
14	Bewaffnung und Ausrüstung	0,5	4,4	20,0	180
15	Oberflächen von Brunnen	0,05	1,1	2,0	45
16	Innenflächen von Anlagen	0,1	2,2	4,0	90
17	Außenflächen von Anlagen	0,5	11,0	20,0	450
18	Küchen- und Bäckereiausrüstungen	0,005	0,005	0,2	0,2
19	Oberflächen von Lebensmittelverpackungen	0,01	0,01	0,2	0,2

Key: (1) Figures given in millions; (2) Standards take effect in response to special instructions; 3--Item; 4--Permissible contamination, beta decays per 1 cm^2 and min; 5--Old; 6--New; 7--Human body surface; 8--Palms; 9--Animal body surface; 10--Mask hood; 11--Underwear; 12--Outerwear, gear, shoes, and personal protective gear; 13--Hand-fired weapons; 14--Armament and equipment; 15--Surfaces of wells; 16--Inside surfaces of installations; 17--Outside surfaces of installations; 18--Kitchen and bakery equipment; 19--Surfaces of food packages.

To estimate the energy dose of beta radiation, Kodochigov[59] gives the following relation:

$$D_\beta = \frac{5{,}8 \cdot 10^{-5} \cdot N_\beta \cdot E_\beta \cdot t}{\Delta} \text{ rad} \qquad (7.50)$$

N_β--Beta particle flow, cm^{-2}/sec^{-1}
E_β--Maximum energy of developing beta spectrum, MeV
t--Irradiation duration, hr
Δ--Whole-value layer of absorption of beta particles of given energy, g/cm^{-2}.

In view of the small dependence of the maximum permissible flux of beta particles on the energy of the prevailing spectrum in the range of up to about 10 MeV, Kodochigov points out that one may therefore consider it permissible, in determining the justifiable surface radioactivities, to start from mean values without considering specific beta energies.

Table 7.19 presents reference values for the maximum permissible surface radioactivities of some important objects. It must be kept in mind that these values must be considered not only from the viewpoint of contact radiation but also from the angle of incorporation danger. Besides, Langhans correctly points out that this table is based on very few reliable initial data.[60]

The problem complex of nuclear radiation monitoring with the help of gamma radiation measurements is explained in detail in the book by Langhans, entitled "Kernwaffenradiometrie und Kernwaffendetonometrie," DMV, Berlin, 1970, PP 87 ff.

7.4.2.2. Protection against Incorporation

If the units are properly equipped and trained, the danger of radiation damage due to incorporation of radioactive detonation products, compared to the radiation exposure caused by external radiation, recedes rather far. Nevertheless, this aspect of the direct effect of radioactive substances on the human organism must also be given a certain amount of attention. By the incorporation of radioactive detonation products we mean their penetration (incorporation) into the organism. Specifically, radionuclides can be absorbed by the body via the respiratory tract (inhalation), the digestive tract (ingestion), and through wounds (inoculation). The size of the radioactive particles, the solubility of the existing chemical compounds, and the condition of the organism during the absorption time interval itself have an effect on the process of incorporation.

In case of unit operations in contaminated areas, the incorporation of radioactive substances with the breathing air represents the greatest danger. In general, one can however expect that the lungs in case of resorption play a considerably smaller role than the digestive system. This is due to the fact that particles with a diameter of $d > 10\ \mu m$ in fact are completely filtered out, those with $d > 5\ \mu m$ at any rate are still filtered out to the extent of 95 percent in the nose and throat region, that is to say, they are filtered out of the respiration air and they are then swallowed. Particles with $2\ \mu m < d < 5\ \mu m$ on the other hand on the average get into the lungs with the flow of air to the extent of about 20 percent and those with $d < 1\ \mu m$ to the extent of about 90 percent. But particles in this order of magnitude account for only a very tiny fraction of the total radioactivity (see Section 7.2.2.1.1).

In addition to swallowing inhaled dust particles, there is another possibility for the penetration of radioactive detonation products via the digestive tract during the consumption of contaminated rations and contaminated water. This absorption of radioactive substances particularly depends on the solubility of incorporated dust particles. Such elements as uranium and plutonium

form difficult to dissolve oxides, while strontium and barium form easily soluble oxides. Radionuclides, which are trapped in larger particles with a melted surface, as a rule are not resorbed but instead are again eliminated in an undigested [undecomposed] fashion.

Wounds constitute another gateway for incorporation. Here, it is especially large and deep wounds as well as wounds caused by large-area burns that constitute a serious threat. Penetration of radioactive substances via the intact skin is also basically possible but need not be covered in the context taken up here.

The radiation exposure of the organism, caused by the incorporation of radioactive detonation products, depends on the absorbed total dose (the cumulative radioactivity), the type of radiation, the energy of radiation emitted, and the particular absorbed share, the organ distribution, and the physical and biological half-life.

Table 7.20. Rough Connection between Incorporated Total Activity of Fission Products and Resultant Degree of Radiation Sickness[61]

Degree of radiation sickness	Incorporation, mCi/kg body weight	
	Absorption through inhalation	Absorption per os
I	0.05	0.1--0.5
II	0.1	1
III	0.3	2 ... 3
LD_{100}	0.5	5

Because radioactive detonation products and the nuclear radiation emitted by them have already been described in detail, it is not necessary here once again to go into all of these factors. Table 7.20 presents some reference values for fission products concerning the degree of anticipated damage as a function of the incorporated total radioactivity.

In contrast to external radiation, incorporation naturally involves some special aspects of the radiation effect. They are based above all on the nearby location of the incorporated radiation sources with relation to some particularly radiation-sensitive cellular tissues, the high local intensity of radiation, and the differing degree of chemical affinity of the various radionuclides with the most important biogenic elements in the organism. Under combat conditions, quite generally, the maximum permissible quantity of detonation products that can be incorporated is considered to be that quantity of which the organism due to beta and gamma radiation receives no more than 0.05 rad and due to alpha radiation no more than 0.005 rad per day. Without going into any further details here, it emerges quite clearly in this context with the data in Table 7.20 what role the age of incorporated radionuclides plays in such considerations.

The incorporated radionuclides become internal radiation sources only if they get into the blood circulation system, if they are transported from there into the tissues and organs, and if they are deposited there.

(In general, the deposit of the various radionuclides in the whole body or in specific tissues and organs, after their resorption, is completed within a few hours.)

We can in a greatly simplifed manner arrange the radionuclides in three groups according to their distribution in the organism. We have those which:

Are deposited primarily in the skeleton, that is to say, in the bones, such as strontium, barium, calcium, thorium, uranium, and plutonium;

Are enriched mostly in the liver, the kidney, and the spleen, etc., such as lanthanum, cerium, polonium, and manganese;

Are distributed over individual organs without characteristic accumulation.

In this connection it must however be observed by way of restriction that, when it comes to organ distribution, the structure of the particular chemical compound, in which the corresponding radionuclide is present, is also significant. Independently of that, one can define certain "critical organs" for radioactive detonation products, that is to say, organs whose damage as a result of internal radiation will signify the greatest damage for the body as a whole.

According to Kutzim, the particular critical organ is determined in the light of the following factors:

"It must:

"(a) Reveal the highest concentration of radioactive material in the body;

"(b) It must be of special significance to the organism as a whole in functional respects among the organs considered;

"(c) The differing biological radiation sensitivity of the individual organs;

"(d) Organ damage, caused by the entry of the radionuclide into the body, must also be considered."[62]

If, in an organ, the mass M of share p of a "radioactivity quantity" A is stored, then the organ, according to Franco[63] will contain U = p · A radioactivity units and, considering the effective half-life, we accordingly get the following integral tissue dose (energy dose):

$$D = 1{,}6 \cdot 10^4 \frac{U \cdot T_{eff}}{M} \quad \text{rad} \tag{7.51}$$

According to Frost, the equation given applies preferably to beta emitters while, in the case of complex emission spectrums, the gamma component must be considered percentage wise.[64]

Looking at the magnitude of the radiation damage caused by incorporated radionuclides, the physical half-life as well as the biological half-life are of significance. It characterizes the average time the particular radionuclide spends in a certain organ or in the body as a whole; that is to say, the time during which half of the incorporated total quantity is again eliminated.

The connection between effective, physical, and biological half-life is given by the following relation:

$$\frac{1}{T_{eff}} = \frac{1}{T_{phy}} + \frac{1}{T_{biol}}$$

or:

$$T_{eff} = \frac{T_{phy} \cdot T_{biol}}{T_{phy} + T_{biol}} \qquad (7.52)$$

Corresponding data for the individual radionuclides of detonation products can be found in tables 7.3, 7.9, and 7.10. In addition to the values for the critical organs, we also have the mean values for the whole body here.

The speed of elimination of incorporated radionuclides depends on many factors. Those radioactive substances which form easily soluble salts are eliminated most quickly whereas those which enter into complex compounds with albumins are eliminated more slowly; radionuclides deposited in or on the skeleton spend the longest time in the body. Elimination itself takes place primarily through the stool and the urine.

According to data by Vogler, the ratio of elimination in case of oral intake (digestive tract) is 9:1.[65] The course of radiation sickness caused by the incorporation of radioactive detonation products differs quite essentially from the one described in Section 5.3.3.2 regarding external radiation (instantaneous nuclear radiation). But because pure incorporation in fact is ruled out under field conditions and because we need not expect any acute radiation damage--that is to say, radiation damage leading to combat disablement--we cannot go into any greater detail here regarding the problem complex of possible delayed damage. We will not make any further statements here.

Protecting units against the danger of incorporation during operations in contaminated zones can in particular be guaranteed by the following:

Timely use of personal protective gear and use of combat vehicles and permanent shelters equipped with filter ventilation systems;

Correct behavior in contaminated terrain;

Compliance with strict ration and water supply schedules and procedures;

Timely implementation of decontamination and medical treatment measures; and

First-aid measures as well as specific therapy for radiation victims by the Medical Corps.

The foundation for this overall complex of protective measures consists of uninterrupted conduct of nuclear radiation monitoring and the goal-oriented analysis of the nuclear radiation situation.

Table 7.21 is a compilation of the most important protective measures and rules of behavior during operations in contaminated terrain.[66]

We can see that putting on the protective mask in moist weather is not absolutely necessary.

Rations for the troops must be protected against indirect contamination by radioactive dust with particularly great care. Basically, this involves simple measures to prevent "radioactive contamination" of essential and non-essential foods during processing, transportation, preparation, and consumption which however are difficult to implement in practice. To understand the complete content of this, one must get away from any preconceived notions to the effect that visible quantities of radioactive dust must be present and that they are the ones which lead to incorporation with dangerous consequences. The exact opposite is the case. For example, theoretically, 1 g of radioactive fission products can lead to the most severe radiation damage in 50,000 people.

Proper packaging is of great importance.

Essential foods, present in cans or in repeatedly sealed plastic pouches, are reliably protected against contamination due to radioactive dust. They can be consumed without worry after careful decontamination of the packaging, regardless of how high the previous surface radioactivity of the package was.

The preparation of ration products and meals in contaminated terrain is complicated inasmuch as there is always a danger here that radioactive detonation products might also be processed along with the food. This danger can be countered effectively by means of careful selection of stationing areas for ration supply services (field bakeries, slaughter sections, kitchen facilities, field kitchens, etc.), preparation of meals under the most hermetical circumstances possible or other fixed installations, partial terrain decontamination or wetting the ground and constant nuclear radiation monitoring. The essential prerequisites for the success of such measures include the fact that all army personnel must fully understand their content and that these measures must be implemented in a disciplined fashion and that the standards and characteristic values in the corresponding service regulations must be strictly complied with.

Table 7.21. Important Protective Measures and Rules of Behavior during Operations in Contaminated Terrain

Protective gear to be used		Rules of behavior and protective measures
In case of dusty air (dry, windy weather, snow-storm)	In case of clean air (moist weather, after rainfall or snowfall)	
Crossing contaminated sectors on foot		
Individual protective gear	Protective stockings, cape and gloves	Speed up march tempo, avoid dust formation, do not touch contaminated objects, bypass sectors with high dose rates
Crossing contaminated sectors mounted on motor vehicles, APC's, and tanks		
Individual protective gear	Protective stockings, cape and gloves	Increase march movement speed, increase intervals, do not touch contaminated objects when dismounting
Crossing contaminated sectors in tanks and closed APC's (without filter ventilation system)		
Mask		Close hatches and shutters, turn fans off
Staying in contaminated terrain		
Mask, protective stockings and gloves	Protective stockings and gloves	Use shelter facilities improved by Engineers and others, avoid staying in sectors with high dose rates, improve shelter facilities, decontaminate, organize meal times and rest in shelters, units operating in sectors with high dose rates must periodically be relieved.

To guarantee the water supply, especially drinking water, we must among other things make full use of the water filtering stations available on the individual echelons; by means of their ion exchanger systems, they guarantee complete decontamination of the water while complying with the prescribed operating rules. It is furthermore possible to cover smaller open watering places or wells and thus to prevent contamination by radioactive dust at the right time. Larger quantities of water must above all be taken from deep wells because natural decontamination takes place in the soil. Constant nuclear radiation monitoring is necessary here likewise. Furthermore, water consumption must be reduced to a minimum. Even lightly contaminated surface water--possibly from flowing water bodies--can be used as utility water, for example, for decontamination.

Because the questions of decontamination and medical treatment are covered in a summarized fashion in Section 7.4.4, we will not go into any further detail here. It must however be observed that one must not view decontamination only from the viewpoint of preventing the incorporation of radioactive substances or additional radiation exposure. Instead, one must keep in mind that wearing protective gear is not possible to an unlimited degree and that this leads to extraordinarily heavy physical and psychological stresses on fightingmen above all when outside temperatures are higher. This can cause a considerable reduction in combat capacity.

Table 7.22 supplements Table 7.19 and contains some important maximum permissible radioactivities for various foodstuffs and other products.[67]

Table 7.22 Important Maximum Permissible Radioactivities for Nuclear Radiation Monitoring of Essential Foods, Fodder, Liquids, and Air (MzA)

Meßobjekt 1	2 β-Zerfallsprozesse je min und je cm²	cm³	g	l	3 α-Zerfallsprozesse je min und je cm²	cm³	g	l
4 Nahrungsmittel und Gewürze bei nur eintägiger Aufnahme	$5 \cdot 10^3$	$5 \cdot 10^4$	–	–	$5 \cdot 10^2$	$5 \cdot 10^3$	–	–
5 Nahrungsmittel und Gewürze bei einer 5tägigen Aufnahme	10^3	10^4	–	–	10^2	10^3	–	–
6 Futtermittel für einige Tage	$5 \cdot 10^3$	$5 \cdot 10^4$	–	–	$5 \cdot 10^2$	$5 \cdot 10^3$	–	–
7 Trinkflüssigkeit bis zu 2 l	–	$5 \cdot 10^4$	$5 \cdot 10^4$	$5 \cdot 10^7$	–	$5 \cdot 10^3$	$5 \cdot 10^3$	$5 \cdot 10^6$
8 Trinkflüssigkeit bis zu 10tägiger Aufnahme	–	$5 \cdot 10^3$	$5 \cdot 10^3$	$5 \cdot 10^6$	–	$5 \cdot 10^2$	$5 \cdot 10^2$	$5 \cdot 10^5$
9 Brauchwasser (Brauchflüssigkeit)	–	$2 \cdot 10^5$	$2 \cdot 10^5$	$2 \cdot 10^8$	–	$2 \cdot 10^4$	$2 \cdot 10^4$	$2 \cdot 10^7$
10 Atemluft bis zu 1stündiger Aufnahme	–	10^2	–	10^5	–	10	–	10^3
11 Atemluft bis zu 10stündiger Aufnahme	–	10	–	10^4	–	1	–	10^2

Key: 1--Object to be measured; 2--Beta-decay processes per minute and per; 3--alpha-decay processes per minute and per; 4--Essential foods and seasonings for only one-day consumption; 5--Essential foods and seasonings for 5-day consumption; 6--Fodder for several days; 7--Drinking liquid up to 2 lit; 8--Drinking liquid up to 10-day consumption; 9--Utility water (utility liquid); 10--Respiration air up to 1-hour absorption; 11--Respiration air up to 10-hour absorption.

7.4.3. Principles of Nuclear Radiation Monitoring and Dosimetry

In preparing a situation estimate after enemy nuclear strikes, one can directly consider only those reconnaissance data that are determined at the right time by the reconnaissance units and that are forwarded to the staffs.

Any decision springing from the specific nuclear radiation situation concerning further unit operations however presupposes a certain minimum of realistic reconnaissance data concerning terrain contamination. The greater the general overview of the nuclear radiation situation in the particular operational area and the more specific reconnaissance data we have available on the directions and areas of interest, the less will be the risk in decision-making in relation to a situation in which we must start only or almost exclusively with an analytical evaluation. This is why the basic requirements for nuclear radiation monitoring and dosimetry spring from the scope and quality of the realistic reconnaissance data required for the purpose of bringing about a decision.

The capacity of a nuclear radiation monitoring system depends--in addition to the number, structure, and equipment of available reconnaissance units--also on an exact arrangement of observation, communication, storage, and analysis of reconnaissance data.

Nuclear radiation reconnaissance is not only a job for the corresponding chemical defense units but concerns all arms of the service, all special units and support services; that is to say, it is carried out not only by special organic groups but also by nonorganic groups.

Nuclear radiation reconnaissance as a whole covers all organs, personnel, equipment, and means serving for the planning, organization, and implementation of measures aimed at the determination, communication, storage, and analysis of reconnaissance data for the evaluation of the directions of propagation of radioactive detonation clouds, the start and duration of radioactive fallout, the determination of the dimensions of contaminated zones and the dose rate levels, their change with the passage of time, as well as the determination of the degree of unit contamination during and after operations in contaminated areas on the basis of dose rate and radioactivity measurements.

Nuclear radiation monitoring is conducted without interruption during all types of combat and in every situation. The reconnaissance agencies here must accomplish specific assignments for the particular command echelon and moreover also supply the higher headquarters with the required reconnaissance data. The employment of available reconnaissance personnel must be so handled that there will be a steady, comprehensive, and as complete as possible overview of terrain contamination in the particular unit operation area.

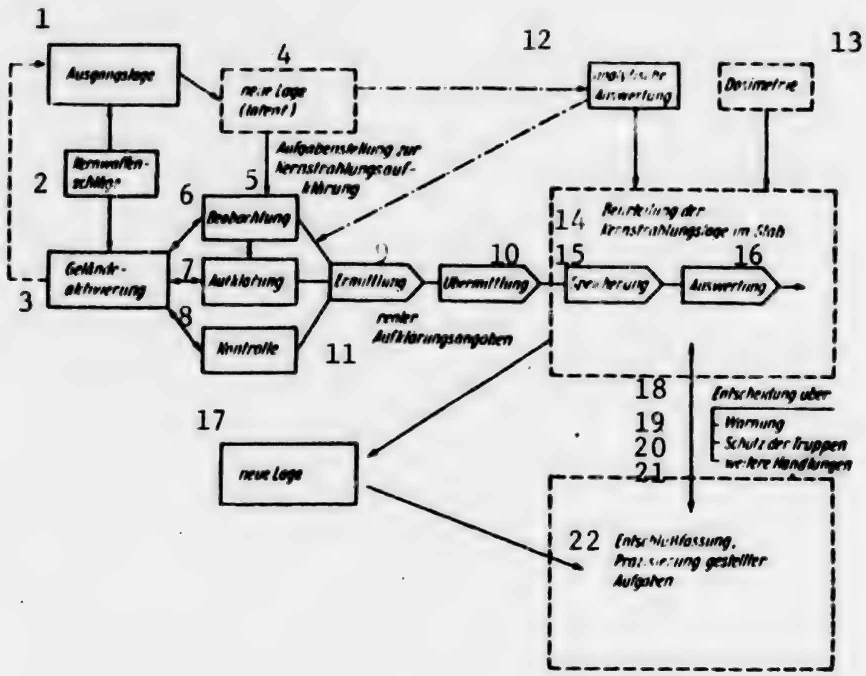


Figure 7.42. Position of nuclear radiation monitoring in the process of nuclear radiation situation estimate preparation. Key: 1--Initial situation; 2--Nuclear strikes; 3--Terrain contamination; 4--New situation (latent); 5--Nuclear radiation monitoring mission; 6--Observation; 7--Reconnaissance; 8--Monitoring; 9--Determination; 10--Communication; 11--Of realistic reconnaissance data; 12--Analytical evaluation; 13--Dosimetry; 14--Nuclear radiation situation estimate preparation by staff; 15--Storage; 16--Analysis; 17--New situation; 18--Decision on; 19--Warning; 20--Protection of units; 21--Further operations; 22--Decision-making, specific definition of assignments given.

This presupposes an adequate density of measurement points, the ability to form points of main effort, and the ability rapidly to switch the main effort in nuclear reconnaissance monitoring into a new direction as well as constant conduct of monitoring and follow-up monitoring which, under the conditions of a complicated nuclear radiation situation, in many cases to begin with facilitates exact evaluation and arrangement of reconnaissance assignments and their machine processing.

In connection with the preparation of the nuclear radiation situation estimate, nuclear radiation monitoring is used to warn the troops of the danger of contamination, the determination and conduct of the necessary protective measures, but also their confinement to the necessary minimum and the drafting of those decisions which will guarantee the accomplishment of the combat mission also in case of high dose rates but which in the process will keep unit casualties due to radiation as low as possible. In first place therefore we do not have dosimetry, that is to say, the determination of the nuclear radiation doses already absorbed by the units, but the advance calculation of the anticipated dose absorption for the purpose of achieving its maximum reduction. This is why the conduct of constant and periodic dose rate

measurements assumes utmost significance. Furthermore, we also need installations which make it possible to conduct special measurements and investigations on the existing contamination of surfaces, foodstuffs, etc. For this we use the laboratory facilities present in the individual command echelons.

Under the conditions of massive nuclear weapon employment, operations and combat actions will be developed in vast areas. The semistrategic structure and the combat deployment pattern will be distingushed by great breadth and depth. There will be great distances and intervals between the individual elements. Combat operations take place at a fast pace, on a broad front, in great depth, and in [several] directions.

This is why an important goal of nuclear radiation monitoring consists not only in rapidly providing a comprehensive overview of the terrain contamination situation but also viewing the situation in long-range terms. This is possible only if the staffs can rely on the reconnaissance data supplied by all reconnaissance agencies which at the particular time happen to be operating in the areas and directions to be analyzed.

In other words, this means that the decision to conduct one or the other type of maneuver in contaminated zones cannot so much be the result of a "specially" conducted nuclear radiation monitoring mission but that this instead must result from a sufficiently broad overall view of the nuclear radiation situation "in itself."

Here are the forms of nuclear radiation reconnaissance:

Nuclear radiation warning,

Nuclear radiation observation,

Nuclear radiation reconnaissance of areas, march routes, and directions, and

Nuclear radiation monitoring.[68]

An exact dividing line between nuclear radiation warning and nuclear radiation observation from the tactical viewpoint is neither possible nor required. A somewhat different viewpoint is derived from the equipment and instrument aspect on which, for example, Langhans builds the organization and listing of radiometric equipment under field conditions.[69]

Nuclear radiation observation is conducted by nonorganic groups for nuclear radiation and chemical reconnaissance (NGKCA), by observers from units of all of the combat arms and from units for nuclear radiation and chemical reconnaissance from one point or while on the move. It is used in determining the start of contamination or reaching a contaminated sector at the right time. This can be done with the help of "organic" reconnaissance instruments or with the help of special nuclear radiation warning instruments which basically operate permanently, which are installed in certain combat vehicles (command vehicles) or also in aircraft, ships, etc., and which trigger an alarm when an adjustable dose rate threshold is crossed.

On the basis of the nuclear radiation reconnaissance of areas, sectors, march routes, and directions, we determine the location, dimensions, and dose rates of contaminated zones, we mark them to a limited extent, we warn the units, and we order the required protective measures. Nuclear radiation reconnaissance can be carried out on foot, with motor vehicles, in armored combat vehicles, and, in the case of naval forces, with ships or boats. Nuclear radiation reconnaissance of the terrain can furthermore be accomplished with helicopters or slow-flying aircraft. It can also partly be carried out with the help of an automated instrument system in which automatically operating measurement instruments pass their measurement results on to electronic computers for processing which, in turn, forward their analysis results to the staffs via information reproduction instruments.

Nuclear radiation monitoring is carried out by the nonorganic groups for nuclear radiation and chemical reconnaissance with simple means and methods and can be supported by organic groups or can be performed in special field laboratories of the chemical, rear-echelon, and medical services. It is the goal of nuclear radiation monitoring to determine the need for or the success of decontamination, to draw conclusions for the further wearing of protective gear, at the right time to identify contaminated foodstuffs or unit supplies, to prevent or restrict their consumption or utilization, and thus quite generally to rule out the possibility of casualties among the troops due to incorporation. Radiation monitoring in medical facilities may also be used for the observation of decorporation.

Nuclear radiation reconnaissance on foot is carried out above all in the form of observation. In well-developed radioactive zones, reconnaissance on foot can accomplish only strictly limited assignments because the scouts after all are exposed to the full dose rate and, besides, because we get only a slow reconnaissance tempo.

During reconnaissance with motor vehicles or armored combat vehicles, it is --in addition to the fast reconnaissance speeds and the possibility for communicating the reconnaissance data immediately via radio over great distances--the protection factors of the vehicles which have a positive effect on employment possibilities. This makes it possible, on the one hand, to limit the time spent in contaminated zones in terms of time and, on the other hand, to reconnoiter areas with relatively high dose rates, assuming the scouts are exposed to acceptable radiation exposure.

The prerequisite here of course is that reconnaissance be carried out with the help of inside measurements. In this case however the attenuation of nuclear radiation by the particular reconnaissance vehicle must be included in determining the measured dose rates.

It has been pointed out variously that work with the reciprocal values of the protection factors according to Table 7.18 is too inaccurate. (As we know, the protection factor for tanks has a mean value of $f_s = 0.1$ [illegible]. Accordingly, a dose rate, measured in a tank's combat compartment, must be multiplied by the correction factor 10 in order to get the dose rate in the terrain.) This is why it is required from time to time to check or newly to

determine the correction factors during reconnaissance missions. This makes it necessary, for a specific measurement point, under otherwise equal conditions, in each case to make one measurement out in the open at a height of 1 m in the terrain and a second one in the vehicle and to compare both values.

$$k_M = \frac{1}{f_s} = \frac{P_{terrain}}{P_{vehicle}} \qquad (7.53)$$

It is even better tc select a corresponding measurement series as foundation for the calculation of k_M.

Available experience enables us to estimate that the inherent contamination of the reconnaissance vehicles during operations in contaminated terrain as a rule can be neglected because the resultant measurement error can here be neglected in comparison to the general measurement inaccuracy. An exception here is involved in the extraordinarily severe soiling of vehicles, such as it is to be expected in case of wet weather and swampy soil. Control measurements are required here.

Nuclear radiation reconnaissance from the air is a kind of reconnaissance which makes it possible to reconnoiter continuing zones of heavy and dangerous contamination also during the first few hours after ground and underground detonations, to get a fast overview of the developing situation, and in the process to enable helicopter crews or crews of slow-flying aircraft to avoid acute radiation exposure. Besides, it is possible in this connection to conduct combined reconnaissance, that is to say, to link the evaluation of detonation areas, large-surface fires, flooded regions, etc., with nuclear radiation reconnaissance.

But one must not overestimate nuclear radiation reconnaissance from the air. This above all concerns a question of time. The employment of helicopters is basically possible only if radioactive fallout in the areas or directions to be reconnoitered has ended--that is to say, at the very earliest 30-60 minutes after enemy nuclear strikes--as a function of the distances from the detonation areas. A disadvantage here is represented by the fact that we get very high measurement errors (up to 300 percent) in nuclear radiation reconnaissance from the air.

The information content of reconnaissance data derived from nuclear radiation reconnaissance in the air depends on a series of factors. The most important ones are the character of existing contamination, the flying altitude, and the flying speed. If one keeps in mind that the flying altitude compared to the surface covered by a contaminated area is small, then the measurement results will nevertheless be influenced by the direction of flight in relation to the position of the radioactive trace. This among other things depends on the inertia (time constant) of the particular measurement instrument. Besides, the values of the correction factors rise rapidly with the altitude over a contaminated surface area. This causes great measurement uncertainties especially in case of heavily-cut terrain where it is difficult to maintain a constant flying altitude.

In general we must expect that the radiation profile in case of reconnaissance from the air will be flattened out and will be shifted in the direction of flight.

The best flying altitudes are between 50 m and 200 m. If we assume an average flying speed of 100 km/hr^{-1} and if we figure that we need 20-30 sec for one measurement, then the distance between the measurement points will be 500-800 m.[70]

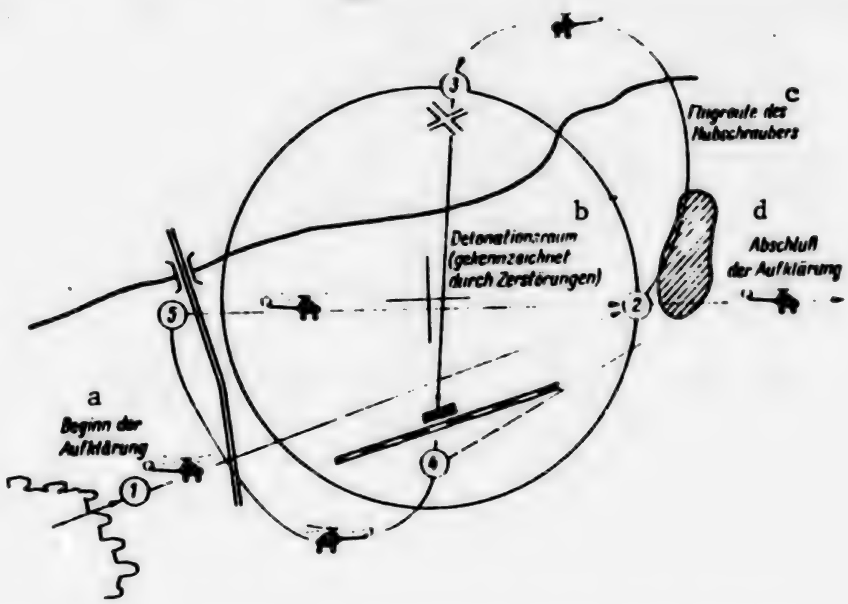


Figure 7.44. Reconnoitering a detonation area from the air. Key: a--Start of reconnaissance; b--Detonation area (marked by destruction); c--Helicopter's flight path; d--Completion of reconnaissance mission.

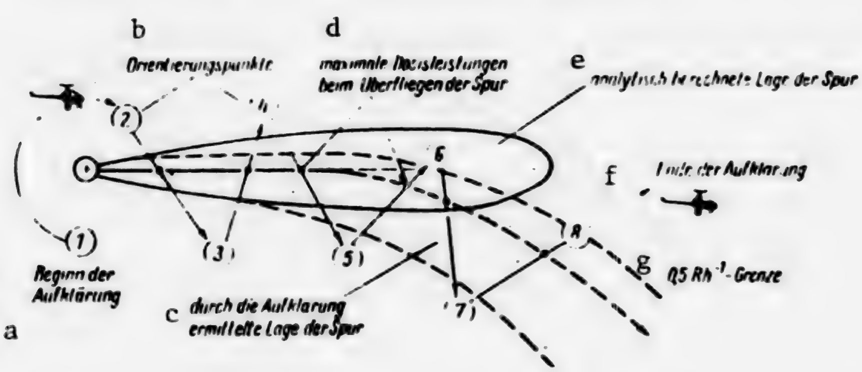


Figure 7.45. Reconnoitering the trace of a nuclear weapon detonation. Key: a--Start of reconnaissance; b--Orientation points; c--Location of trace determined by reconnaissance; d--Maximum dose rates while overflying trace; e--Analytically calculated location of trace; f--End of reconnaissance mission; g--Boundary.

The most important assignments which can be accomplished by means of airborne nuclear radiation reconnaissance include the following:

Rough reconnaissance of detonation areas,

Determination of location of zones with heavy and dangerous contamination,

Reconnaissance of areas, march routes, and directions, and

Checking on the decline in the dose rates with the passage of time.

Airborne reconnaissance and ground reconnaissance must be coordinated. On this basis, it is possible especially to define the operations of nuclear radiation and chemical reconnaissance units more specifically and to conduct reconnaissance missions efficiently in support of the combat mission to be carried out.

Because of the relationship between the orders of magnitude of unit operation areas and the orders of magnitude of the possible contaminated zones, certain graduated requirements for nuclear radiation reconnaissance spring from the general information requirement of the staffs to guarantee an overall picture of the nuclear radiation situation.

These requirements consist first of all in specifically spelling out the directions of propagation of the radioactive detonation products or the location of contaminated zones; second, the determination of the orders of magnitude of terrain contamination if possible in the entire operation area; and, third, the detailed reconnaissance of important areas and directions for further unit operations.

In the transmission of reconnaissance data from the reconnaissance agencies to the staffs, one must assume that each unit or measurement station, upon observing a case of contamination, must immediately send a report. If this involves radioactive fallout, then this first message is in the nature of a warning in which it is as a rule not necessary to give specific dose rates. For the duration of radioactive precipitation, further reconnaissance reports make sense only to a certain degree and must clearly be marked as messages reporting trends. A reconnaissance report "which can be evaluated" must be forwarded however in each case immediately after the end of radioactive fallout. In addition to the forwarding of reconnaissance data from the reconnaissance agencies to the staffs, information exchange is also necessary between staffs. But here the data must in each case be condensed to avoid any superfluous redundancy.

Concerning the forwarding and exchange of data on terrain contamination as a result of nuclear radiation reconnaissance we can basically distinguish three types of reports: warning reports, reconnaissance reports, and evaluation reports.

Warning reports are messages on the start of radioactive fallout or the appearance of terrain contamination. They can be given by specifying the place

and time in the form of a uniform signal. Trend reports are to be handled like warning reports. Their forwarding must be extensively restricted.

Reconnaissance messages are messages on dose rate measurements that were performed after termination of radioactive fallout or in case of well-developed contamination. They can be forwarded as individual or collective reports from the reconnaissance agencies to the staffs and between them. Reconnaissance reports contain the coordinates of the measurement places, the astronomic times of the measurements, and the dose rates measured.

Analysis reports are reconnaissance messages which have been processed by the staffs and are used to report to the superior staff or for the information of subordinate staffs. An analysis message on an area contains the highest dose rate in that area; in case of a direction (march route) it contains the average dose rate of the direction or march route. The sizes of areas or sectors, for which a "maximum" or "average" dose rate can be specified, will depend on the specific situation and the character of the existing contamination.

In connection with analysis reports it is a good idea to convert and relate the dose rates uniformly to the time of detonation (or detonations). This is why it is not necessary to indicate the individual measurement times. Analysis reports therefore contain only the moment of detonation (detonations), the coordinates of the area or direction, and the relative dose rates. If a given terrain contamination cannot be matched up with a certain detonation time, then only the forwarding of reconnaissance reports is possible between staffs, although typical measurement values or measurement stations can be selected.

Concerning the sequence (valence) connected with the forwarding of reconnaissance and analysis reports, we can distinguish four categories which must be matched up with the differing priorities:

Reconnaissance data without reference to analytical evaluation;

Reconnaissance data contradicting analytical evaluation;

Reconnaissance data further spelling out analytical evaluation;

Reconnaissance data confirming analytical evaluation.

This kind of approach to the analysis of reconnaissance data on terrain contamination cannot only correspondingly reduce the volume of the information flow but can also guide analysis work effectively toward the particular main effort and determine the sequence of processing the incoming messages.

In conclusion it might be observed regarding this problem complex that, under the conditions of a complicated nuclear radiation situation, we get not only contradictory reconnaissance data but, in keeping with the development of terrain contamination in terms of space and time, we will get data which can be evaluated immediately and data which cannot be evaluated

immediately and they will arrive more or less simultaneously at the various headquarters. This means that the dose calculations, performed on this basis, will have a differing information content. This is why it is not correct to say that nuclear radiation reconnaissance must "specifically spell out" the analytical advance calculation of terrain contamination in each case. Instead, this is a complicated reciprocal process which must always be viewed from the time aspect involved in decision-making.

Nuclear radiation reconnaissance is meaningfully supplemented by nuclear radiation dosimetry. (In general terminology, we normally use the abbreviated term "dosimetry" which likewise clearly includes the given situation.)

Nuclear radiation dosimetry (dosimetry) includes all methods of measurement, recording, and analysis of nuclear radiation doses absorbed by the troops after nuclear weapon detonations due to the effect of instantaneous nuclear radiation, during combat operations in contaminated zones, and when handling radioactive substances.

Dosimetry is used primarily to prevent the absorption of high nuclear radiation doses, to guarantee a constant overview of the impairment of the combat capacity of the major and minor units and formations due to radiation exposure, and to get guidance values for medical care to be given to radiation victims.

Dosimetry is carried out in the form of group dosimetry (squads, vehicle and gun crews), and in the form of individual dosimetry. The dosimeters constantly remain with the soldier and are periodically or in case of heavy radiation exposure checked according to special determinations. Depending upon their purpose, we can subdivide dosimeters basically into two groups. The first group includes the tactical, direct-reading dosimeters which make it possible constantly and directly to check on the nuclear radiation dose absorbed; the second group includes the individual dosimeters which must be read with the help of a special analysis instrument and which can be designed both as short-term and as long-term dosimeters.

It must however be pointed out that tactical or group dosimetry can be accomplished also with not-directly-indicating dosimeters, provided the analysis instruments are distributed down to the companies and platoons.

The nuclear radiation doses are recorded, they are added, considering the biological decay of the radiation effect (see Section 5.3.3.2), and they are analyzed and evaluated in tactical and medical respects. In this connection it must be pointed out that the specification of average radiation exposures for minor units makes sense only if the differences in dose absorption of the individual fighting men are not too great.

7.4.4. Principles of Decontamination and Medical Treatment

Special treatment assumes an important place in the complex of measures to eliminate the consequences of enemy attacks using mass annihilation means.

Special treatment encompasses all of the work designed to remove (or render harmless) radioactive substances, CW and BW agents from surfaces of various objects or from supply items to such an extent that direct or indirect damage to human beings can be ruled out and so that subsequent operations will be possible without the need to wear protective gear.

Accordingly, "special treatment" is a collective term for radioactive decontamination, chemical decontamination, and biological decontamination. To the extent that special treatment involves the individual directly, it is called medical treatment.

In special treatment (medical treatment) we distinguish between partial and complete treatment forms. This subdivision takes into account the fact that, under combat conditions, the above-defined goal of special treatment cannot in each case be attained fully and in one step.

Partial special treatment must be administered immediately after contact (radioactive contamination, chemical contamination, biological contamination). It contans above all the removal of contamination products from the surface of the human body, protective gear, and parts of combat vehicles, combat equipment, etc., with which personnel will constantly come into contact during the accomplishment of combat missions. The need for the continued wear of protective gear is not removed as a result of partial special treatment.

Complete special treatment calls for the complete removal (the rendering harmless) of contamination products, including secondary radiation products, within the above-mentioned definition. Concerning medical treatment, it normally includes a change of clothing.

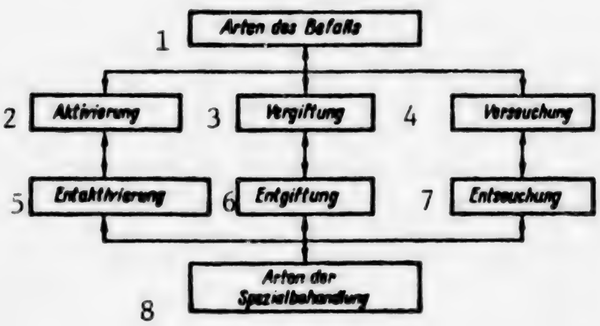


Figure 7.46. Types of special treatment. Key: 1--Types of contamination; 2--Radioactive contamination; 3--Chemical contamination; 4--Biological contamination; 5--Radioactive decontamination; 6--Chemical decontamination; 7--Biological decontamination; 8--Types of special treatment.

While partial special treatment is carried out primarily with the help of individual decontamination pouches, group decontamination sets, and using local expedients in the particular combat deployment or march movement pattern on orders from the particular commander or independently, complete special treatment as a rule is administered after the accomplishment of combat assignments on orders from the higher superior at PSB (special treatment places) or in RSB (special treatment rooms) and it can be supported by chemical defense units (medical service units). As we go on, we only touch on some questions of radioactive decontamination and pertinent medical treatment.

The most important peculiarity in radioactive decontamination consists in the fact that the decay of the radioactive detonation products cannot be influenced in any way. This is why, in case of radioactive decontamination, we can only remove the radioactive substances, we cannot render them harmless. Radioactive decontamination in terms of the absolute reduction of existing radioactivity takes place only due to the natural decay of the radionuclides with the passage of time after detonation. In this context, there is a "most favorable" and "latest" point in time, under combat conditions, for the performance of radioactive decontamination from the viewpoint that one must compare the required effort and the resultant benefit attained. This kind of determination however does not include the fact that any radioactive contamination, even the slightest one, can lead to damage.

During radioactive decontamination and medical treatment, we use physical, chemical, and mechanical methods.

They are based, in the sequence mentioned, on washing off radioactive substances with active washing solutions or solvents, the removal of radioactive particles from the surfaces of objects by means of a highly-compressed gas-fluid jet, the transformation of water-insoluble products into water-soluble products and their subsequent removal by washing, methods of precipitation of radioactive substances from liquids, and methods of ion exchange as well as simple rubbing off, lifting off, scratching off, sucking off, beating out, etc.

Active-washing, complex-forming, and ion-exchanging substances are particularly suitable as radioactive decontamination agents.

Active-washing substances are high-molecular compounds which are easily soluble in water, which reveal boundary-surface-active properties (increase in flexibility and in the dirt-removing effect of aqueous solutions). As an example here we might only mention Mersolat D. But most of the commercially available detergents are also suitable as radioactive decontamination agents.

Complex-forming substances can, because of their property of entering into complex compounds with other substances, be used for radioactive decontamination. With their help it is possible to dissolve and then remove radioactive particles which have been absorbed on the surface. This, for example, is very important in clothing decontamination in order to increase the effectiveness (use of complexones, for example, Chelaplex III).

Ion-exchanging substances are used primarily to remove radioactive substances which have been dissolved in water. By means of the combined use of anion-exchanging and cation-exchanging substances, one can take water thus contaminated and completely purify it by removing the dissolved radioactive substances while suspended substance-filters are necessary to retain solid radioactive contamination.

When we must radioactively decontaminate large equipment items, thorough washing with water will in many cases not suffice to attain the necessary degree of decontamination even if any adhering dirt has first been removed

from those items. This can be explained by the fact that the radioactive particles are not deposited on the surfaces as such but instead stick to them and are almost throughout water-insoluble. If we furthermore consider that both the surfaces of combat vehicles and those of combat equipment are painted with lacquers and paints which have a water-repellent effect, with the same also applying to certain impregnated clothing items, then we can even better understand the previously mentioned observation and the necessity of intensive mechanical processing and the use of active-washing decontamination liquids.

On the basis of what we have said so far, we must however not immediately conclude that unpainted metal surfaces are more easily decontaminated than painted ones. The exact opposite is the case. The radioactive particles stick extraordinarily well to oxidized surfaces. This is why it is a good idea also to use complex-forming agents and weak acids or lye solutions, plus of course active-washing substances. This considerably increases the effectiveness of decontamination but means that the surfaces thus treated will rust quite heavily. But that can be counteracted with the help of corrosion inhibitors or some other kind of immediate rust protection treatment.

Thorough washing with warm water and laundry soap is enough in the case of medical treatment of personnel to remove about 95 percent of the radioactive substances from the skin surface. This is why we need not use any additional decontamination agents under combat conditions. Casualties may constitute an exception here.

Earlier we made reference to the purification of drinking water by removing radioactive contamination. In addition to filtration using ion exchange, coagulation, distillation, and electrodialysis are also important here. We may furthermore assume that, in a series of cases, ordinary mechanical filtration of contaminated water by means of earth and sand filters can result in a purification degree of 50-98 percent because hardly more than 2 percent of the radioactive detonation products are soluble in water. If the water is heavily contaminated, that of course will not be enough and one must therefore consider mechanical filtration as an expedient.[71]

The situation is similar in the case of coagulation (deflocculation), using iron and aluminum salts which above all are suitable for the removal of relatively large suspended-substance particles.

On the other hand, distillation gives us pure drinking water. It is however connected with a comparatively major effort and must periodically be interrupted because of the heavy enrichment of radioactive substances in the distillation residues. Electrodialysis is still in its initial stages of development. It basically involves the use of anion-exchanging and cation-exchanging selectively permeable membranes, whereby separation is speeded up by the application of an electrical field.

We cannot go into any greater detail here regarding the special question of radioactive decontamination of foodstuffs. We explained earlier that, in the case

of canned foods, surface decontamination is completely sufficient. If the radioactive particles have gotten directly on or into the foodstuffs, then "decontamination" is under certain circumstances conceivable by means of removal (cutting off) of the upper, contaminated layer. If that is not enough, then foodstuffs thus contaminated must be stored until the natural decay of the radioactivity of the radionuclides below the maximum permissible standards and if that is not possible, they must be destroyed.

The decontamination of roads and terrain sectors or the creation of lanes in contaminated zones is not the rule but rather the exception and is confined to command agencies, communications centers, field hospitals, etc. All available earth-moving machines and street-cleaning vehicles are used for these tasks. The main method in terrain decontamination involves lifting off the upper contaminated layer of dirt. In the case of roads with a corresponding surface constitution, radioactive substances can also be partly hosed off or they can at least be sprayed with water and dust development can thus be reduced. But the effectiveness of all of these measures is poor.

Units have comprehensive technical equipment available for decontamination and medical treatment (special treatment). For detailed information, reference is made to the book by Blumenstein although it is no longer up to date on the latest development level in all questions.[72]

The equipment of the National People's Army with special treatment equipment is in line with the tendency to the effect that the main effort in special treatment is being shifted more and more toward implementation with the personnel and resources of the major and minor units themselves. This is why one must distinguish equipment items and gear present in the units directly and those items which are included among the special equipment of chemical defense units.

There is a close connection between the equipment, the instruments, and the individual gear, on the one hand, and the goals, types, means, and methods for special treatment, on the other. According to the special treatment assignment to be accomplished, we can distinguish four groups:

Equipment, instruments, and individual gear for medical treatment of personnel;

Technical gear and equipment for special treatment of combat equipment, armament, and equipment items;

Technical equipment and instruments for special treatment of clothing, protective gear, and special supply items (including water);

Equipment for special treatment of objects, installations, and terrain sectors.

Without going into any further detail, we will explain some examples below. Shower facilities (DA-66) are used to perform complete medical treatment. They consist of a system vehicle and a trailer with the necessary accessories (showers, tents, etc.). In addition to shower water, the unit can produce

hot water up to 90° C and it can generate steam; it can also heat decontamination liquid to 50-60° C and this liquid can be discharged via special working lines.

To perform complete special treatment of combat equipment and armament, we use systems and special vehicles which permit the continuous spraying of decontamination liquids (chemical and biological decontamination liquids) or also pressurized water. Here, we can use not only vehicles with larger tanks, from which several work stations must be supplied (ARS-12u), but also vehicles with autonomous special treatment instruments (ES-65). Earlier we made reference to the possible use of gas-jet (liquid-jet) turbines. The ASR-12u is a tank car with a capacity of 2,500 lit. A pump driven by the vehicle's engine is used to fill the tank and generate pressure for the spray nozzles and the steel pipes. All accessories (hoses, spray nozzles, distributors, etc.) are attached to the vehicle itself. The EA-65 comprises 16 transportable instruments with a capacity of 40 lit liquid, each. They are unloaded for special treatment from the transport vehicle with the help of unloading devices. The tanks are filled from the ARS-12u. The necessary compressed air is generated by a compressor plant and, prior to distribution, it is piped into the tanks (working pressure 4-6 kp/cm^{-2}) so that no further auxiliary facilities are necessary at the particular work stations.

The most customary methods for special treatment (especially chemical and biological decontamination) of clothing and equipment are based on the use of hot-air, steam, steam-formalin mixtures, cooking, washing, and rinsing processes, and they are carried out with special systems.

In conclusion it might be noted that a whole series of locally available means and installations can be used for special treatment, particularly for radioactive decontamination. This includes open-air pools, laundries, repair bases, etc., which can considerably supplement and expand the organic possibilities for special unit treatment.

Review Questions

7.42. Define the concept of nuclear radiation situation. What connection is there between terrain contamination, residual nuclear radiation, and the nuclear radiation situation?

7.43. Explain the thesis to the effect that the nuclear radiation situation restricts unit operations in terms of time and space.

7.44. What types of maneuvers do we distinguish to reduce the radiation exposure of troops during combat operations in contaminated zones?

7.45. Mention the maximum permissible nuclear radiation doses for combat conditions. How must these values be interpreted?

7.46. Compare the protection factors of combat vehicles and shelters with respect to instantaneous and residual nuclear radiation.

7.47. What are the basic principles we must use in calculating the anticipated dose absorption by the troops? How accurate are such computations?

7.48. What is the significance of possible incorporation of radioactive substances?

7.49. With the help of some practical examples, explain the most important measures for protecting units against incorporation.

7.50. What is the essential content of behavior rules during operations in contaminated terrain?

7.51. What are the maximum permissible radioactivities and how must we work with these values?

7.52. What is the mission of nuclear radiation reconnaissance? Explain the forms of nuclear radiation reconnaissance.

7.53. Compile the performance possibilities and typical operational variants of nuclear radiation reconnaissance on foot, with combat vehicles, and with helicopters. Compare the advantages and disadvantages in each case.

7.54. What types of reports on terrain contamination can be forwarded from the reconnaissance agencies to the staffs and between the staffs?

7.55. Explain the content and organization of dosimetry. (Note that the nuclear radiation doses from instantaneous nuclear radiation must also be recorded.)

7.56. Why is it wrong to believe that the difference between partial and complete special treatment (decontamination) boils down to whether support is or is not given by chemical defense units?

7.57. What methods can be used for decontamination and medical treatment? Explain them with the help of some examples.

7.5. Footnotes for Chapter 7

1. These questions are presented in a continuing manner in Section 7.4.1.

2. We used the following values in compiling the data in Table 7.1:

   Radioactivity of Pu-239: 60 Ci kg^{-1}
   Radioactivity of U-238: $3 \cdot 10^{-4}$ Ci kg^{-1}
   Radioactivity of Fission Products: $2 \cdot 10^{12}$ Ci kg^{-1}
   Efficiency of nuclear fission of Pu-239: η = 20%
   Efficiency of nuclear fission of U-238: η = 15%.

3. More detailed data on the fission products developing from the fission of various nuclear explosives due to neutrons of differing energy can be found among others in Katcoff, S., Nucleonics 18 (1960) 11, pp 201 ff.

4. The table was taken over unaltered from Lavrenchik, V. N., "Global'noye vypadeniye produktov yadernykh vrtsyvov," Atomizdat, Moscow, 1965, p 12 f. (This work also contains a compilation of Soviet and American original studies on this topic complex.)

5. Ibid., p 8.

6. The picture was copied in a simplified manner from Strauss, H., "On the Determination of Maximum Permissible Concentrations of Radioactive Fission Products in Drinking Water for Disaster Cases," SZS Report, 3, 1967, p 15.

7. Additional statistics can be found among others in Leipunskiy, O. I., "Gamma Radiation from Nuclear Weapon Detonations," Moscow, 1959, Russian; Langhans, K., "Kernwaffenradiometrie und Kernwaffendetonometrie," German Military Publishing House, Berlin, 1970; Zakutinskiy, D. I., and others, "Spravochnik po radioaktivnykh izotopov," Moscow, 1962.

8. Way, K., and E. Wigner, Phys. rev. 73 (1948) p 1318.

9. Levochkin, F. N., and Yu.Ya. Sokolov, Atomnaya energiya, 10, 1961, p 403.

10. Petrov, R. V., and others, "Zashchita ot radioaktivnykh osadkov," Medgiz, Moscow, 1963, p 166.

11. The values in the table were partly taken from Petrov, loc. cit., p 167.

12. The picture was taken from Lavrenchik, V. N., "Global'noye vypadeniye...," loc. cit., p 15.

13. In the literature reviewed, data for the average energy of beta and gamma radiation vary up to 25 percent from the figures given in Table 7.5. We cannot go into any greater detail here regarding the reasons for this. It may merely be noted that the gaseous detonation products were not included in the computations.

14. Spencer, L. V., "Structure shielding against fallout radiation from nuclear weapons," Washington, National Bureau of Standards, Monograph 42, June, 1962, Russian edition from Atomizdat Publishing House, Moscow, 1965, p 14.

15. Bjoernerstedt, R., Arkiv foer Fysik 16 (1959) 28, pp 293 ff.

16. For comprehensive information on the term of the effectiveness [action] cross-section used here, reference is made to "Kleine Enzyklopaedie Atom, Struktur der Materie" [Small Encyclopedia, Atom, Structure of Matter], VEB Bibliographic Institute, Leipzig, 1970, pp 150 ff. In a greatly simplified manner we might say this: The action cross-section is a measure of the yield of a nuclear reaction. As the probability of the materialization of a certain reaction, it is made up of the penetration probability (in the special case of neutrons) and the conversion probability. For illustration purposes we can assume that

an atomic nucleus, bombarded with certain particles, will oppose the flow of projectiles with a certain cross-section. As a unit of measure for this action or effectiveness cross-section we use the surface area of 10^{-28} m which roughly corresponds to the geometric cross-section of heavy nuclei and we label it as 1 barn.

17. On this problem complex, see also Yampol'skiy, P. A., "Neytrony atomnogo vtsryva," Gosatomizdat, Moscow, 1961, Chapter 2.

18. Lavrenchik, V. N., "Global'noye vypadeniye...," loc. cit., pp 18, 19.

19. Ibid., pp 21-23.

20. Ibid., p 23.

21. The table was compiled with the help of data from Langhans, K., "Kernwaffenradiometrie ...," loc. cit., p 58, and DV-66/3, MfNV 1963, pp 366.

22. See also DV- 66/3, loc. cit., p 366 ff.

23. The Plowshare Program, Appl. Atomics (1962) 4, p 353.

24. Nifontov, B. I., and others, "Podzemnye Yadernye vtsryvy," Atomizdat, Moscow, 1965, pp 80 ff.

25. See also Langhans, K., "Kernwaffenradiometrie...," loc. cit., p 35.

26. Other necessary numerical data for computations to be made can be found among others in the following works: "Kleine Enzyklopaedie Atom, Struktur der Materie," VEB Bibliographic Institute, Leipzig, 1970; Haissinsky, M., and J.-P. Adloff, "Principal Characteristics and Applications of the Elements and their Isotopes," New York, 1965, Russian edition from Atomizdat Publishing House, 1968; Gordeyev, I. V., and others, "Yaderno-fizicheskiye konstanti," Gosatomizdat, 1963.

27. Gusev, N. G., "Leitfaden fuer Radioaktivitaet und Strahlenschutz," [Guide for Radioactivity and Radiation Protection], VEB Technical Publishing House, Berlin, 1957, p 80.

28. Langhans, K., "Kernwaffenradiometrie...," loc. cit.

29. Gosev, N. G., "Leitfaden fuer Radioaktivitaet ...," loc. cit., p 81.

30. On this problem complex, see also Christofilos, N. C., "The Argus Experiment," J. Geophys. Res. (1959), pp 1699 ff.

31. In addition to special military models, this among other things involves models of atmospheric mixing and circulation and exchange models. In this connection see also Machta, L., and others, A Survey of Radioactive Fallout from Nuclear Tests, J. Geophys. Res. 67 (1962), p 1389;

Staley, D. O., On the Mechanism of Mass and Radioactivity Transport from Stratosphere to Troposphere, J. Atm. Sci 19 (1962), p 450; Libby, W. F., Moratorium Fallout and Stratospheric Storage, J. Geophys. Res. 68 (1969) p 2933 and p 6215; Lavrenchik, V. N., "Global'noye vypadeniye ...," loc. cit., Fuchs, S., "Mathematical Methods for the Approximate Determination of Terrain Contamination and the Resultant Conclusions for the Commander," dissertation, The Friedrich Engels Military Academy, 1964.

32. Problems connected with detonations in the ionosphere and outer space are not considered in the following presentations.

33. See also Lavrenchik, V. N., "Global'noye vypadeniye ...," loc. cit., p 147; Langham, W., and E. C. Anderson, "Fallout from Nuclear Weapons Tests Hearings 1959," US Govern. Print. Office, Washington, 1959, p 1068.

34. The picture was taken from Budzhko, V., T. Bukalskiy, "Meteorologichne problemy prognozovaniya skazen," Mysl Woyskova, 1964, 4, p 54.

35. Ibid., p 55. (The picture was redrawn.)

36. The Wahnsdorf Meteorological Observatory was kind enough to make the picture available for which we want to express our appreciation. See also Zier, M., "On the Global Transport of Fission Products of Past Nuclear Weapon Tests in the Atmosphere and Their Appearance in the GDR," MILITAERWESEN, 1965, 5, p 685.

37. On this problem complex see Kusin, P., "Ten Million Victims in One Generation," PROBLEME DES FRIEDENS UND DES SOZIALISMUS [Problems of Peace and Socialism], 1959, 9, pp 51 ff.

38. Zier, M., "On the Global Transport ...," loc. cit., p 685 f.

39. See also Fuchs, S., "Mathematical-Physical Considerations on Terrain Contamination after Nuclear Weapon Explosions," MILITAERWESEN, 1954, 11, p 1602.

40. The picture was changed and was taken from Timofeyev, B. N., and Yu. K. Nesytov, "Prognozirovaniye radioaktivnogo zarazheniya," Publishing House of the USSR Defense Ministry, Moscow 1969, p 12.

41. Ibid., p 14. (The type of illustration was altered.)

42. The conversion of these values for other times after detonation will be explained in Section 7.3.

43. On this problem complex, see Boehme, F., and K. Mendel, "On the New Method of Analytical Evaluation of Nuclear Weapon Strikes," MILITAERWESSEN, 1966, 7, pp 990 ff.

44. The picture was taken from Nifontov, B. I., and others, "Podzemnye ...," loc. cit, p 71.

45. Ibid., p 84.

46. The treatment of this problem complex is impossible without a major mathematical effort. If necessary, this section can be skipped, except for the conclusions given.

47. Fuchs, S., "Mathematical Methods for the Approximate Determination of Terrain Contamination and the Resultant Conclusions for the Commander," dissertation, "Friedrich Engels" Military Academy, 1964, pp 113-116.

48. Spenser, L. V., "Structure shielding ...," loc. cit., pp 39 ff.

49. The values of this function among others are given in Jahnke-Emde, "Tafeln hoeherer Funktionen" [Tables of Higher Functions], B. G. Teubner Publishing Company, Leipzig, 1952, 5th edition, p 1 and pp 6-9.

50. In general we can say that, if we include multiple scatter in the calculations, we get dose rate values which are about 25-50 percent higher than shown in Formula 7.29. Because of the uncertainty of the initial values, this however plays only a subordinate role in many cases in rough estimates.

51. The k-values can be taken from the pertinent service regulations.

52. In Table 34 of DV-36/2, the distribution of the integral nuclear radiation dose is not related to 1 hour after detonation but rather to the "duration of nuclear radiation from the moment of radioactive trace formation on." Because of that, the values given differ somewhat from each other.

53. On this problem complex, see Rudloff, A., "Determination of Dose Rate and Dose in Case of Superposition of Fallout Fields from Several Detonations," "Zivilschutz," 1962,2, pp 60-64.

54. The term "analytical evaluation" is used here in the sense of theoretical advanced calculations on the basis of the results of nuclear weapon detonations with the help of tabulated fallout models, etc.

55. This subdivision into "technical" and "semistrategic-tactical" measures of protection activities is by no means intended to create a formal dividing line. It is however practical for methodological reasons and permits clear statements.

56. DV-36/2, p 40.

57. That such a statement can be made emerges from the fact that the measurement errors for gamma radiation are considerably higher.

58. Petrov, R. V., and others, "Zashchita ot radioaktivnykh osadkov," loc. cit., pp 70 ff.

59. Kodochigov, P. N., "Oprakticheskikh voprosakh dozimetrii ioniziruyushchikh izlucheniy," Izdatel'stvo akademii nauk SSSR, Moscow, 1962, p 30.

60. The table was taken from DV 053/0/003.

61. The table was taken from special reprint "Radiation Damage" by the Military-Medical Information and Documentation Office, Ernst Moritz Arndt University, Greifswald, 1967, p 5.

62. Quoted from Kutzim, H., ATOMKERNENERGIE, 7, 1962, 12, p 487.

63. Franco, V. H., and others, Medical Sciences, Vol. I, Pergamon Press, Ltd., London, 1956, quoted from Frost, D., "Praktischer Strahlenschutz," Berlin, 1960, pp 11 ff.

64. Ibid., p 13.

65. On this problem complex, see Vogler, H., "Incorporation--Decorporation," Information Service of the NVA, Military Medicine Series, No 5, 1971, pp 37 ff.

66. The table was compiled on the basis of Table 22 in DV-36/2, p 26.

67. The table was taken over unaltered from Langhans, K., "Kernwaffenradiometrie ...," loc. cit., p 87.

68. On this problem complex, see DV-36/1, pp 25 ff.

69. See also Langhans, K., "Kernwaffenradiometrie ...," loc. cit., pp 72 ff.

70. On this problem complex, see Hoffmann, M., "On Radiation Reconnaissance Using Helicopters," MILITAERWESEN, 1962, 5, pp 713 ff.

71. Petrov, I. G., "Dezaktivatsiya, degazatsiya i dezinfektsiya, Zhurnal vsesoyuznogo Khimicheskogo obshchestva, 18, 1968, 6, pp 699-703.

72. Blumenstein, W., "Entigftungs- und Entaktivierungsgeraete" [Chemical and Radiological Decontamination Instruments], German Military Publishing House, Berlin, 1965, 225 p.

8. Nuclear Weapon Protection as Integral Component of Unit Protection against Mass Annihilation Weapons

8.1. Summary of Most Important Measures of Unit Nuclear Weapon Protection

In the introduction to this textbook we already observed that unit nuclear protection is an integral component of unit protection against mass annihilation weapons and must in all combat types and in every situation be organized with the goal of preventing the use of mass annihilation weapons to the maximum extent, reducing the effects of enemy attacks, preserving or rapidly restoring the combat value and combat readiness of units, and to guarantee the accomplishment of the combat mission.

This objective means that we can have protection of units against mass annihilation weapons only if it is a properly planned, organized, and implemented task and if it is made the content of the work of all commanders and staffs as well as all arms of the service, special units, and supporting units, even if the enemy has not yet used any mass annihilation weapons.

The constant guarantee of unit protection against mass annihilation means is a most profoundly creative task which calls for in-depth evaluation of the situation and decision-making full of initiative and without any stereotype approach.

The partly still existing practice of subdividing measures for the protection of units against mass annihilation weapons into so-called active and passive measures is at least impractical because it no longer does justice to the significance of the individual measure and above all because it gives a false basic orientation.

Table 8.1 summarizes once again and clearly presents the most important measures of unit nuclear weapon protection. But because these measures have already been explained in detail in the past chapters, we need not make any further statements here.[1]

The prerequisites and foundations for constant and all around implementation of protection against mass annihilation weapons in combat must be created today to the fullest extent in the training of commanders, staffs, and units. This in particular makes it necessary to have a clear concept as to the essence and effect of mass annihilation weapons, to be convinced as to the necessity and possibility of protection, and to develop in depth and train the theoretical and practical knowledge and skills absolutely necessary for this. Here, the conviction as to the victorious nature and the defense worthiness of socialism, combined with courage, steadfastness, and the readiness to sacrifice, will play a decisive role.

The external conditions and phenomena of a nuclear missile war lead to extraordinarily heavy psychological-moral and physical stresses on commanders, staffs, and troops. They are caused by the simultaneous action of a large number of influencing factors. They include sudden and crass changes in the situation as a result of enemy attacks with mass annihilation weapons, the appearance of mass casualties, the forced stay in areas with high dose rates, the need for rapid decision-making even when there is no big picture as to the developing situation, repeated and long-lasting operations while wearing protective gear and many others among the problems covered in the preceding chapters.

Table 8.1. Compilation of the Most Important Measures for Unit Nuclear Weapon Protection

Measures	Content of Measures
Timely reconnaissance of enemy preparations for the employment of mass annihilation weapons and prevention of employment of these weapons	Coordinated, uninterrupted employment of all reconnaissance agencies of the arms of the service, special units, and supporting units;
	Reconnaissance of the deployment, movement, and firing positions of nuclear weapons, nuclear weapon depots, places for the preparation of nuclear charges, etc.;
	Immediate destruction of such observed objects by using all available means, such as the rocket forces and artillery, the air forces, special reconnaissance and demolition teams raders.
Advance determination of contaminated areas as well as specific indication of areas in which we find comprehensive destruction, fires, or floods resulting from nuclear weapon employment	Evaluation of enemy's specific possibilities for the employment of nuclear weapons on the basis of the existing situation (nuclear weapons, ranges, detonation intensities, detonation types, targets);
	Possibilities for the employment of ground and underground bursts in particular (character of operations, high-altitude weather situation, areas for laying nuclear mines, anticipated nuclear radiation situation);
	Evaluation of particularly endangered directions and areas (cities, woods, dams, lakes regions, impassable terrain sectors, introduction and deployment sectors for the second echelons and reserves, forced-crossing sectors, etc.);
	Consideration of conclusions deriving from situation estimated for decision-making and assignments to units;
	Forward-looking analysis of the effects of enemy nuclear strikes on the accomplishment of missions and scope of measures to eliminate consequences;

Measures	Content of Measures
Permanent organization and conduct of nuclear radiation reconnaissance	Uninterrupted reconnaissance of the most important areas, sectors, march routes, and directions by organic and nonorganic nuclear radiation and chemical reconnaissance groups; Determination of the points of main effort for reconnaissance, practical distribution of forces and resources, timely assignment to the reconnaissance units, guaranteeing steady command and communication; Conduct of calculations as to the probability of unit radiation exposure.
Timely warning of units and rear-area logistic support services as to decontamination	Utilization of all available communications and communications equipment; Determination of uniform signals and sequence of warning message transmission; Forward-looking analysis of propagation directions of radioactive detonation clouds; Timely transmission and analysis of reconnaissance data for nuclear radiation situation.
Decentralization and camouflage of field units and rear-echelon logistic support services	Complete utilization of available area for stationing and deployment of units; Maintenance of specified distances, intervals, and safety distances; Avoidance of impermissible unit concentrations during the introduction of second echelons and reserves, at river crossings, road junctions, etc.; Implementation of measures of camouflage, sham concentration areas, concealment of unit movements, exploitation of nighttime for regrouping, limiting time spent in areas.

Measures	Content of Measures
Change of standby areas for units, basing of air units, as well as positions of ships	Disorientation of enemy reconnaissance by means of covered stationing of units and high varied operations;
	Consideration of enemy's reconnaissance possibilities and timely shift of units from endangered areas;
	Irregular change of standby and assembly areas, unit basing, and stations;
Use of individual protected gear as well as exploitation of protective properties offered by combat vehicles, terrain, and cover [shelters]	Guarantee of high level of protective training and constant action readiness of protective gear;
	Use of natural protective properties of terrain for unit stationing and movement on the battlefield;
	Stay in combat vehicles, positions, and shelters.
Preparation of roads for maneuver and Engineer-technical improvement of areas to be occupied by units	Evaluation of possible terrain-altering effects of enemy nuclear strikes (passability of roads and trails, bridges, possible floods, fire zones, etc.);
	Reconnaissance of the road and trail network, implementation of repair work, strengthening the carrying capacity of bridges, placing signs on roads and trails;
	Improvement of positions and shelters (shelter facilites) and constant increase in their degree of protection with maximum use of natural protective properties offered by the terrain, the existing built-up areas, etc.
Practical action in contaminated areas	Strict implementation of protective measures and behavior rules while staying in radioactively contaminated terrain;
	Restricting the times spent in zones with high dose rates or bypassing such zones or waiting for radiation to decay before crossing them.

Measures	Content of Measures
Dosimetry and nuclear radiation monitoring	Constant advance computation of anticipated unit radiation exposure ;
	Regular analysis of dosimetry (measurement, records, evaluation of possible effects on combat capacity, conclusions concerning further employment) ;
	Dispatch of instant reports in case of high dose exposure or dispatch of daily collective reports corresponding to the determinations specified;
	Nuclear radiation monitoring after leaving contaminated area or after complete decontamination;
	Regular check on unit supplies, such as rations, water, clothing, and gear concerning existing contamination (taking samples, laboratory tests).
Hygienic and preventive measures	Prevention of incorporation of radioactive substances (ban on the use of captured rations, local resources, water from watering places not cleared, etc.);
	Implementation of strict ration and water supply system;
	Administering radiation protection substances
Timely and constant supply of units with protective gear	Determination of sequence and main efforts of supply movements;
	Deadlines, type and place of supply or pickup ;
	Staggering of unit supplies and reserves;
	Utilization of local resources after clearance.
Fast elimination of consequences of enemy use of mass annihilation weapons	(This question is separately covered in Section 8.2.)

Considering the realization that unit command primarily means individual leadership and that, even in the most complicated situation, the unity of political and military leadership must be guaranteed, one may therefore view the protection of units against mass annihilation weapons not simply as a sum of individual measures, decisions, and orders but one must rather understand that this can be done only on the basis of a specific and goal-oriented political effort in combat, in a planned, organized, and effectively executed manner. Here one must not overlook the fact that the constant and direct threat to life can trigger individual reactions, such as fear and mental inhibitions, combined with physical performance decline, as well as group reactions, such as fear and panic.

Among the factors which restrict the possibility of a panic, a central position is held by the political and morale condition of the troops and the knowledge that the cause for which they are fighting is a just one. But specific knowledge as to the possible dangers and the countermeasures to be taken also play an important role.

This is why it is necessary to prepare the troops for the demands of a nuclear missile war. In this connection, impermissible simplifications are just as harmful as uncritical exaggerations.[2] We need no further explanation here to show that, if we bring out and illustrate the realistic conditions of a nuclear missile war unleashed by the imperialists, strict limits will be placed on combat training. Regardless of this, the realistic combat training and preparation of the troops assume great importance. Their implementation above all requires:

The guarantee of a high theoretical training level,

A consistent fight against simplifications and the easy way out in combat training,

The implementation of the knowledge that practice cannot be considered as a criterion by itself,

The basic principles and standards of protecting units against mass annihilation weapons must not simply be considered quantitative requirements but rather qualitative necessities,

The existing training base and time must be used to the maximum extent for realistic combat training,

Complicated initial situations must be created in all combat training, that is, situations whose mastery requires maximum psychological and physical efforts.

Only the close tie-in of political motivation of the combat mission and military skills will create the guarantee for the accomplishment of the military mission. This political and morale education last but not least calls for the collective attitude of each member of the military service, it shapes character and will qualities and guarantees the superiority of socialist soldier personalities. In this connection, resoluteness, self-control,

and the certainty of victory on the part of all superiors and the example they set in every situation are of outstanding significance because they have a stimulating effect on the actions of the subordinates. The need for psychological preparation results from the mastery of demoralizing environmental factors in combat and from the problem arising from the interrelationship between man and technology. An important goal here is to develop an active attitude, that is to say, not to allow any passively tolerating and suffering behavior. In this connection, the confidential relationship of trust between superiors and subordinates is very important. It must be so developed that the subordinate even in complicated situations will be convinced and will remain convinced that the superior is doing everything he can to win victory over the enemy, to preserve the combat readiness of units under his command, and to avoid senseless sacrifices.

These psychological aspects must be considered in the creation of the most realistic possible situations in combat training. This is why such training elements, which demand the constant overcoming of fear and anxiety, have a high educational value. This is possible, without creating really dangerous situations in combat training, if the required safety regulations and protective measures are consistently complied with and carried out and if the particular requirements correspond to the training level.

Summarizing, we can say that, to attain a high level in unit training for protection against mass annihilation weapons, the important thing is:

To use all possibilities for the political and morale permeation of training,

To develop a vast wealth of ideas in the creation or description of situations that come close to modern combat, and

Systematically to train those elements and actions which must take place rapidly and "automatically" in combat.

Review Questions

8.1. Name and explain the most important unit nuclear protection measures.

8.2. Why is nuclear weapon protection an essential component of protection against mass annihilation weapons to begin with?

8.3. With the help of Table 8.1, try to develop some main points in nuclear weapon protection for units as a function of the individual types of combat. Why is it not correct to speak of special and unusual aspects in this context?

8.4. What is the meaning of "implementation of the unity of political and military leadership" under the conditions of mass annihilation weapon employment by the enemy?

8.5. What personal conclusions did you draw from the study of the problems of nuclear weapons and nuclear weapon protection for your own work?

8.6. To what extent can and must the prerequisites for all around and successful implementation of unit protection against mass annihilation weapons be created during the training of the commanders, staffs, and troops?

8.2. Tasks of Commanders and Staffs in Preparing Situation Estimate after Enemy Nuclear Strikes and in Organizing and Implementing the Elimination of the Consequences[3]

Even after enemy nuclear weapon strikes, the primary mission of commanders and staffs is to guarantee the further accomplishment of the assigned combat mission to the maximum extent. The extent to which that is possible will of course depend on the specific effects of the particular enemy nuclear weapon strikes.

By means of thorough evaluation of the arising situation, oriented toward main points, it is necessary to create prerequisites in order to restore the combat readiness of the major and minor units involved in the shortest time possible.

The elimination of the consequences of an enemy nuclear strike specifically encompasses the following:[4]

Restoration of unit command;

Reconnaissance of areas hit;[5]

Rescue work, medical treatment, and evacuation of casualties;

Special treatment (radioactive decontamination and medical treatment);

Clearing and restoration of march routes, restoration or construction of shelters and barriers as well as extinguishing and controlling fires that hinder unit operations;

Nuclear radiation monitoring and dosimetry;

Decontamination of unit supplies, especially rations and preparation of water.

The restoration of unit command is the prerequisite and basic condition for the accomplishment of all other tasks. This among other things springs from the fact that the situation, arising after an enemy nuclear strike, as a rule will be confused and that incoming messages and information will be contradictory. Regardless of that, commanders and staffs cannot wait with their decision-making and with their assignments until they have the big picture. This is why, in such a situation, all deliberations, situation estimates, and calculations must be based on the particular most unfavorable variant as the basic variant.

Considering the combat mission assigned to the units, enemy action, the position of units at the time of the nuclear strike, the specific terrain

conditions, and weather conditions, the commanders and staffs must evaluate the probable casualties, the possible psychological effects on the directly or indirectly hit units due to shock and panic, as well as the terrain-altering effects of nuclear weapon detonations and their influence on the accomplishment of the combat mission. Just exactly how accurately this can be done will depend on the available initial data. If data on the type of detonation are not available, then one must for the time being figure on a ground burst.

Earlier we pointed out that, under certain conditions, the terrain-altering effects of nuclear weapon detonations can be very great. This includes not only large and heavily contaminated craters but also large-area fires, rubble zones, roadblocks, floods due to broken dams and obstruction of rivers, impassability of valleys, gorges, etc.

The analysis of these problems will yield not only conclusions as to the further course of combat but also on the scope and degree of complexity of rescue work to be done.

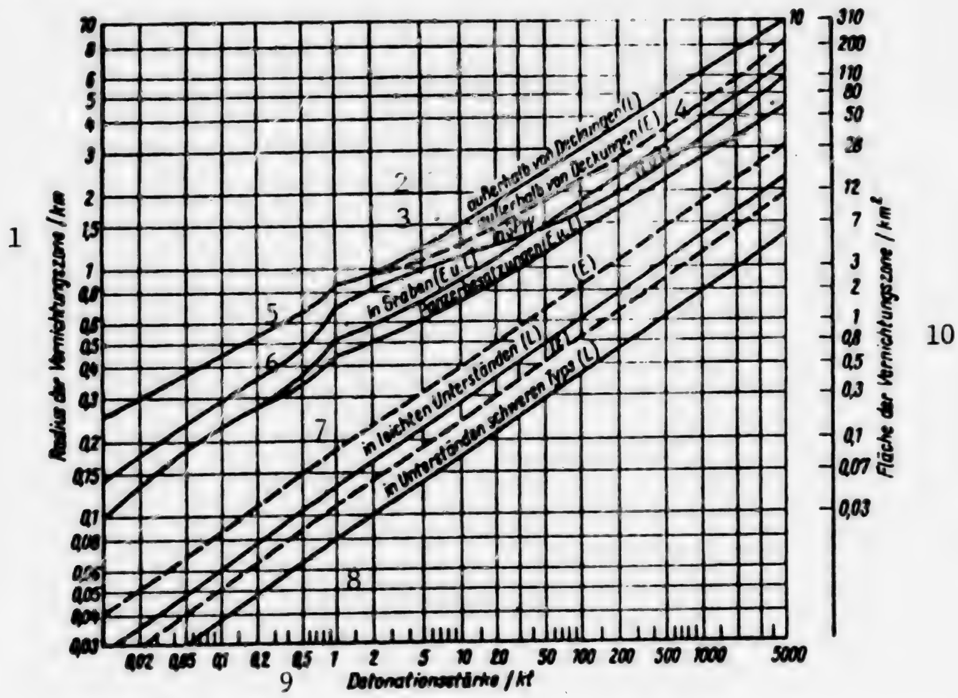


Figure 8.1. Radii of destruction zones as a function of the protection status; (L) Air burst; (E) Ground burst; if the difference in the annihilation radii are small, then both values were combined. Key: 1--Radius of annihilation zone, km; 2--Outside shelters (L); 3--Outside shelters (E); 4--In APC; 5--In trenches (E and L); 6--Tank crews (E and L); 7--In lightweight shelters (L); 8--In shelters of the heavy type (L); 9--Detonation intensity, kt; 10--Surface area of annihilation zone, km^2.

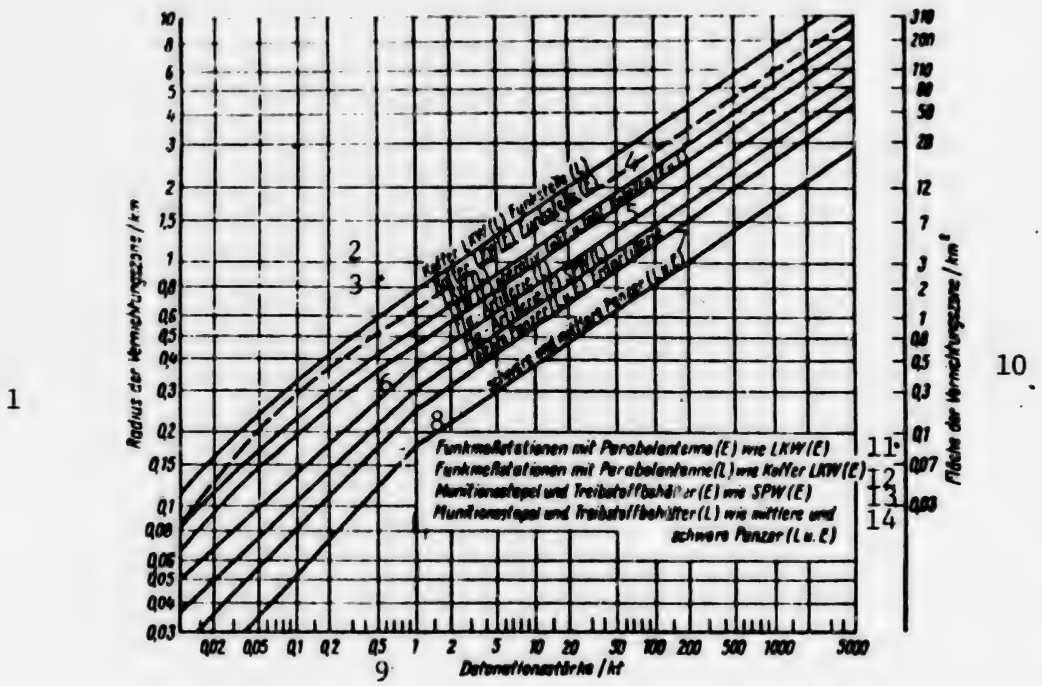


Figure 8.2. Radii of annihilation zones for combat vehicles and combat equipment. Key: 1--Radius of annihilation zone, km; 2--Truck body superstructure, (L), radio station (L); 3--Truck body, (E), radio station (E); 4--Truck (E) [illegible],semistrategic and tactical as well as tactical rockets (E and L); 5--AA artillery (L); 6--AA artillery (E), APC (L); 7--Light tanks (L and E), field artillery; 8--Heavy and medium tanks (L and E); 9--Detonation intensity, kt; 10--Surface area of annihilation zone, km^2; 11--Radar stations with parabolic antenna (E) same as truck (E); 12--Radar stations with parabolic antenna (L), same as truck body (E); 13--Ammunition stack and fuel tanks (E) same as APC (E); 14--Ammunition stack and fuel tank (L), same as medium and heavy tanks (L and E); LKW--truck.

Other difficulties arise from the fact that one must in addition figure on heavy terrain contamination.

Because of the justified assumption that the enemy will always try to make maximum use of the results of his nuclear strikes, much attention must be devoted to the rapid restoration of the fire and barrier system. In this context, increased significance must be assigned to the clearing of important march routes, the restoration of convoy routes, and other measures to guarantee freedom of maneuver, especially for the second echelons and the reserves.

Rescue work in detonation areas encompasses the following:

Searching for victims and rescuing them from combat vehicles and from destroyed or damaged installations;

Rendering first aid;

Evacuation of casualties for further medical treatment at dressing stations.

It is characteristic of the course of rescue work that, as a rule, measures involved in the removal of wreckage, fire-fighting, and clearing march routes and trails must be carried out simultaneously. In addition we have the fact that the particular degree of terrain contamination can essentially influence the course of rescue work.

The combined character of casualties, damage, and destruction resulting from nuclear weapon detonations requires the simultaneous and concentrated use of rescue and recovery detachments whose numerical strength and makeup must correspond to the particular task to be accomplished. The practical implementation of such a requirement, especially in case of massive enemy strikes, however is not always possible to the fullest extent. It is last but not least for this reason that the immediately involved major and minor units must, along with the restoration of combat readiness, organize self-aid and mutual assistance and efficiently start to eliminate the consequences of such strikes without mostly waiting for aid and support from superiors. The sooner we start with the elimination of the consequences, the less will be the anticipated secondary losses and the more quickly can the demoralizing effects be brought under control and the more effectively can we fight against anxiety and panic reactions.

There is no question that even the best-organized unit protection system against mass annihilation weapons cannot completely prevent heavy losses and casualties. But it is indeed possible to minimize the absolute level of these losses by making sure that the commanders, staffs, and troops in the field will theoretically and practically be fully prepared for the problems to be solved in combat, and for the protection of units against mass annihilation weapons.

In his speech to the personnel of the National People's Army on [the Island] of Ruegen in January 1972, First Secretary, Central Committee, Socialist Unity Party of Germany, Erich Honecker made this observation : "In the present-day world, which has been altered by the force of socialism and which keeps changing, imperialism can no longer attain its goals the way it did 30 or 50 years ago. Nevertheless, it remains aggressive, insidious, and dangerous. As the barbaric war adventures against the peoples of Vietnam, Cambodia, Laos, and in the Arab states show, the enemy will not shy away from letting weapons speak, where and when he detects the slightest chance of carrying out his plans of aggression. Nobody can get around that. We therefore have every reason not to let up a single minute in our political and military vigilance. Our image of the enemy is accurate. There is nothing to be changed in that image because the enemy himself has not changed."[6]

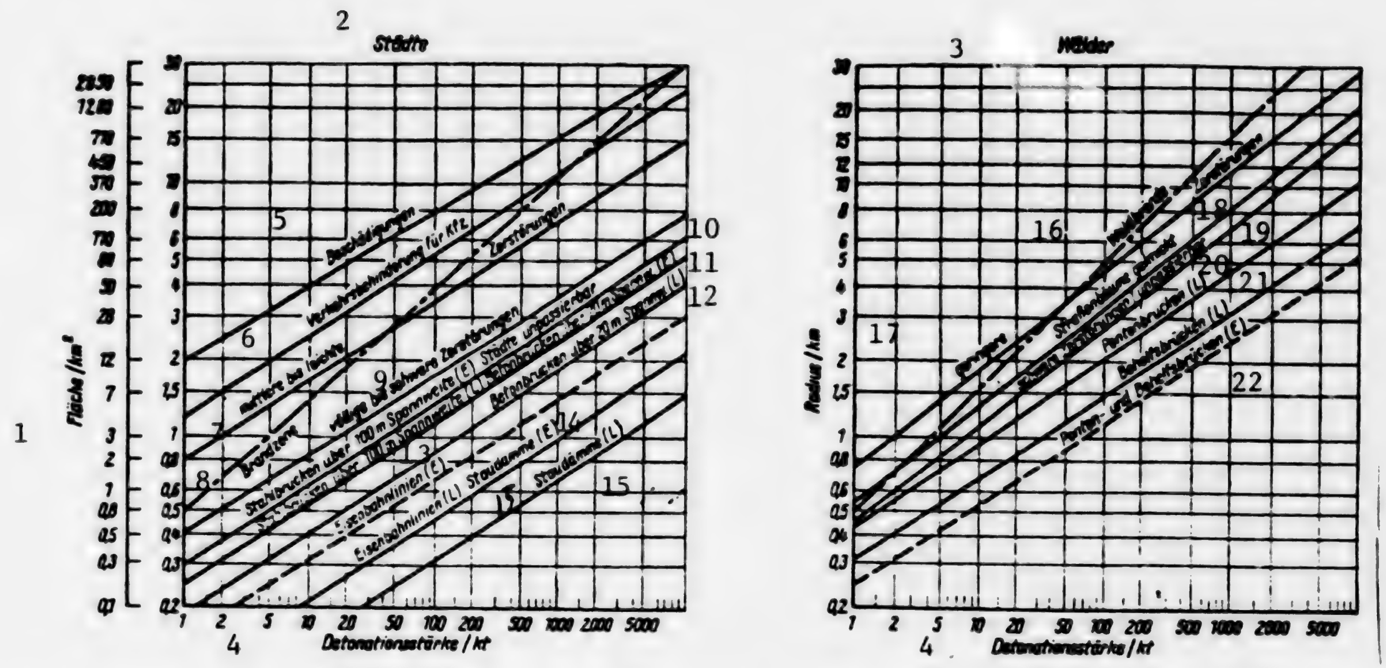


Figure 8.3. Radii of destruction zones in woods and cities as well as various traffic installations (reference values). Key: 1--Surface area, km^2; 2--Cities; 3--Woods; 4--Detonation intensity, kt; 5--Damage; 6--Traffic obstructions for motor vehicles; 7--Medium to light destruction; 8--Fire zone; 9--Complete to heavy destruction; 10--Steel bridges with more than 100 m span (E), cities, impassable; 11--Steel bridges with more than 100 m span (L), concrete bridges with more than 20 m span (E); 12--Concrete bridges with more than 20 m span (L); 13--Railroad lines (E); 14--Railroad lines (L), Dams (E); 15--Dams (L); 16--Forest fires; 17--Minor destruction; 18--Trees lining roads broken; 19--Heavy destruction, impassable; 20--Pontoon bridge (L); 21--Emergency bridge (L); 22--Pontoon and emergency bridges (E).

Review Questions

8.7. What measures are included in the elimination of the consequences of enemy nuclear strikes?

8.8. What special aspects apply to the elimination of the consequences of nuclear strikes under the conditions of severe terrain contamination?

8.9. What are the tasks of the rescue and recovery detachments? Derive their practical makeup in terms of manpower and equipment from that.

8.3. Footnotes for Chapter 8

1. See also Christians, H., "Comments on General Measures for Protecting Units Against Mass Annihilation Weapons," MILITAERWESEN, 1961, 1, pp 175-184; Nadirov, Yu. S., and others, "Zashchita podrazdeleniy ot oruzhiya massovogo porazheniya," Publishing House of the USSR Defense Ministry, Moscow, 1968, p12 p.

2. On this problem complex, see among others, Gillert, H., "On the Panic Problem in Modern Combat," MILITAERWESEN, 1962, 1, pp 51-62; Konieczny, St., "Panic in War," MILITAERWESEN, 1968, 6 pp 843-854.

3. In keeping with the selected organization of this textbook, there is no intention here to cover this problem complex systematically and completely in terms of content. Instead, we want to express some summarizing thoughts. In studying this chapter, one must therefore especially stress the tie-in with the subject matter presented in Sections 2.3, 3.5, 4.3, 5.3, 6.3, and 7.4.

4. DV-36/1, pp 45 ff.

5. The term "area hit" in this formulation does not do justice to the existing situation because this does not exclusively involve the question of nuclear radiation reconnaissance but rather concerns comprehensive reconnaissance of the overall situation arising after enemy nuclear strikes. Nevertheless, it was retained for the sake of uniform terminology.

6. Quoted from the Republic edition of NEUES DEUTSCHLAND [New Germany], 7 January 1972, p e.

List of Formula Systems Used

Generally valid, known symbols were not included in this list. The same applies to those symbols which were used only in a very special context and which therefore are not understandable by themselves alone.

A	Radioactivity Horizontal shift of earth's surface Mass number	A_f	Area [surface] radioactivity

A_1	Neutron induced radioactivity
A_v	Volume radioactivity
B	Buildup factor
C	Speed of sound in air Specific radioactivity
c	Speed of light
c_γ	Heat storage capacity
D	Nuclear radiation dose (ion dose of gamma radiation) Speed of blast wave
D_1	Integral Nuclear radiation dose
D_n	Dose of Neutron radiation
D_W	Horizontal diameter of detonation cloud
D_γ	Gamma radiation dose
d	Thickness Diameter
d_A	Diameter of pileup zone
d_H	Diameter of cavity in underground detonations with complete internal effect
d_{opt}	Diameter of detonation crater in case of optimum crater volume
d_p	Diameter of plastic deformation zone
d_R	Diameter of fissure formation zone
d_s	Diameter of visible crater
d_V	Diameter of condensation zone from underground detonations with complete internal effect
d_W	Diameter of real crater
$d_{1/2}$	Half-life layer of gamma radiation attenuation
E	Energy
E_B	Binding energy
E_{Det}	Detonation energy (total energy)
E_{kin}	Kinetic energy
E_L	Total energy of light radiation
E_{max}	Maximum energy
E_{Sp}	Energy released per atom nucleus split
E[illegible]	Energy released during fusion of two atomic nuclei
E_W	Contamination energy
$\bar{E}$	Average energy
E_γ	Energy of gamma quantum
E_β	Energy of beta particle
e^{-K}	Permeability factor of light radiation in air
F	Surface area Force
F_{KL}	Surface of nuclear charge
f[illegible]	Attenuation [protection] factor of combat vehicles and shelters against gamma radiation from residual nuclear radiation
H_D	Detonation altitude
$-H_D$	Detonation or placement depth
$H_{D_{equ}}$	Equivalent (reduced) detonation altitude
$H_{D_{opt}}$	Optimum detonation altitude
$-H_{min}$	Minimum necessary detonation depth or "line of least resistance" for nuclear weapon detonations with complete internal effect
H[illegible]	Fallout-safe detonation altitude
$-H_{opt}$	Optimum detonation depth
$-H$[illegible]	Reduced detonation or placement depth
H[illegible]	Climbing height of detonation cloud (cloud center)
H[illegible]	Climbing height of detonation cloud from ground burst
H[illegible]	Climbing height of detonation cloud from underground burst

H_z	Astronomic clock time of nuclear weapon detonation
$\bar{H}$	Altitude of upper cloud boundary
$\underline{H}$	Altitude of lower cloud boundary
h	Fallout altitude of radioactive particle
	Planck's action quantum
	Altitude [height]
h_A	Height of crater pileup
h_{opt}	Depth of detonation crater with optimum crater volume
h_S	Depth of visible crater
h_W	Depth of real crater
I_{ges}	Light energy radiated from surface of fireball per second
I_γ	Intensity of gamma radiation
I_0	Intensity of light radiation
K	Attenuation coefficient of light radiation for air
K^+	Scatter coefficient of light radiation for air
K'	Absorption coefficient of light radiation for air
k	Boltzmann constant
	Neutron multiplication factor
	Proportionality factor
k_a	Absorption coefficient of light radiation
k_d	Penetration coefficient of light radiation
k_r	Reflection coefficient of light radiation
k_γ	Dose constant
l	Length
m	Mass [weight]
	Attenuation factor of absorber against neutron radiation
N	Neutron number
N_A	Avogadro constant
N_β	Beta particle flux
n	Number of fission cycles
	Attenuation factor of absorber against gamma radiation
P	Dose rate from gamma radiation
P_{max}	Maximum dose rate
$P_{1\,h}$	Dose rate 1 hour after nuclear detonation
$P_{1\,km}$	Dose rate at kilometer point 1
$\bar{P}$	Average dose rate
p	Pressure [blast]
Q	Charge mass with efficiency η
Q'	Charge mass with efficiency $\eta = 1$
q	Detonation intensity [power]
R	Radius of fireball
	Radius of contaminated surface area
R_{equ}	Equivalent radius of fireball
$R_{equ(max)}$	Maximum equivalent radius of fireball
R_1	Radius of fireball during first period of its development
R_α	Range of alpha radiation
$R_{\beta\,(max)}$	Maximum range of beta radiation
$\bar{R}$	Average radius of fireball (radius of fireball at time of second temperature maximum)
r	Radius
	Distance
r_0	Distance from ground zero
S	Visibility range
s	Path [distance]
	Distance [segment]

T	Thermodynamic (absolute) temperature
T_{biol}	Biological half-life
T_{eff}	Effective half-life
T_t	Transmission factor of light radiation
T_{min}	Temperature minimum at end of first period of fireball
T_{phy}	Synonym for physical half-life $T_{1/2}$
$T_{1/2}$	Physical half-life
t	Time
	Time duration
t_a	Start of radiation effect
t_{Ausf}	Time duration of fallout of radio-active particles from detonation cloud
t_b	End of radiation effect
T_L	Duration of light from fireball (radiation time of light radiation)
t_m	Average time between two nuclear fissions
	Measurement time
$t_{Niederschlag}$	Start of radioactive fallout
$t(T_{max})$	Time of second temperature maximum of fireball
t_1	Duration of first development period of fireball
	Reference time
t_2	Duration of second development period of fireball
	Reference time
U	Light pulse
	Speed of air in blast wave
U_W	Heat pulse
V	Volume
V_L	Charge volume
V_T	Volume of detonation crater
v	Speed [velocity]

v_M	March movement speed
v_o	Initial velocity
$\bar{v}$	Speed of average wind
	Average speed
W	Work
	Separation work for one electron
w	Average fallout velocity of radioactive particle from detonation cloud
Z	Proton number, nuclear charge number
z	Number of nuclear fissions
Δ(Delta)	Whole-value layer of absorption of beta particles of given energy
ΔE_I	Ionizing energy
Δt	Time difference
	Time between two measurements
Δp	Overpressure
Δp_d	Dynamic pressure (impact pressure)
Δp_f	Overpressure along blast wave front
Δp_r	Reflection overpressure (reflection pressure)
ε (Epsilon)	Contrast threshold value of light radiation
η (Eta)	Efficiency
λ(Lambda)	Wavelength
	Heat conductivity
μ (My)	Linear attenuation coefficient of gamma radiation
μ_{eff}	Effective attenuation coefficient
ν (Ny)	Frequency
ϱ (Rho)	density
σ (Sigma)	Stefan-Boltzmann constant (radiation constant)
	Action cross-section
τ (Tau)	Time duration
τ_+	Duration of overpressure phase of blast wave
τ_-	Duration of under pressure phase of blast wave
φ (Phi)	Angle of incidence of light radiation.

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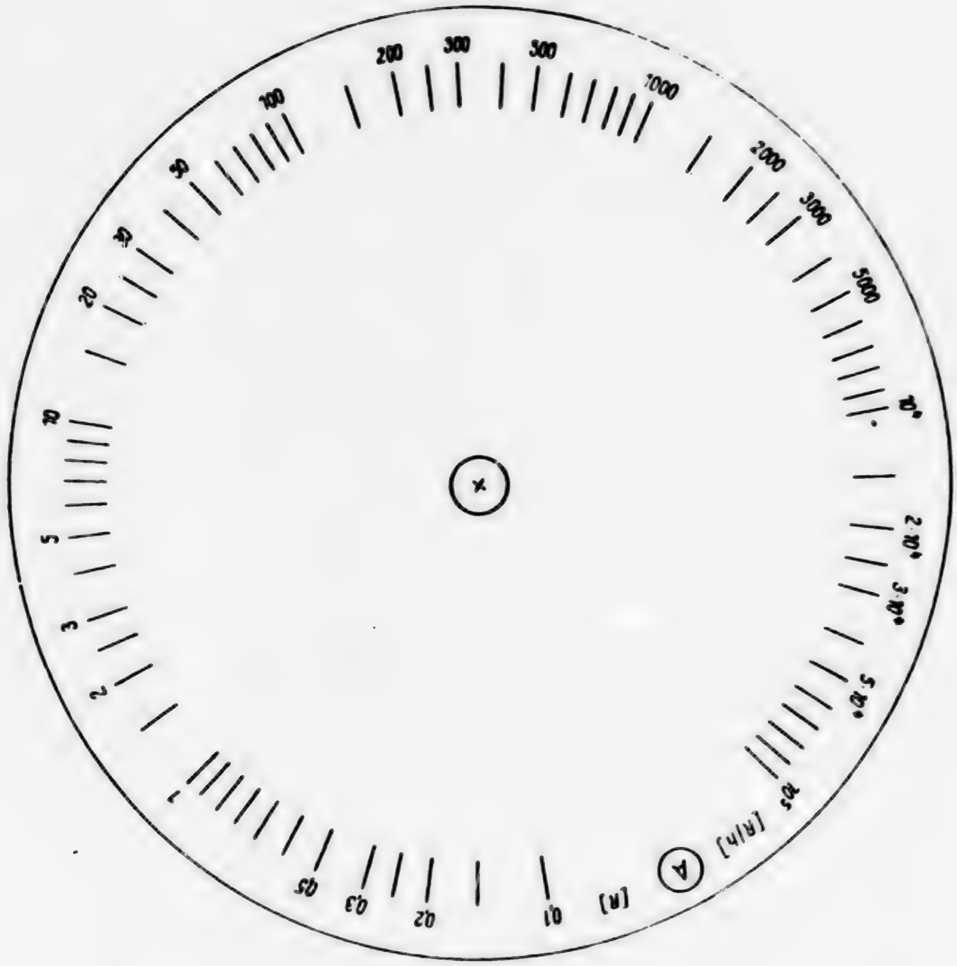

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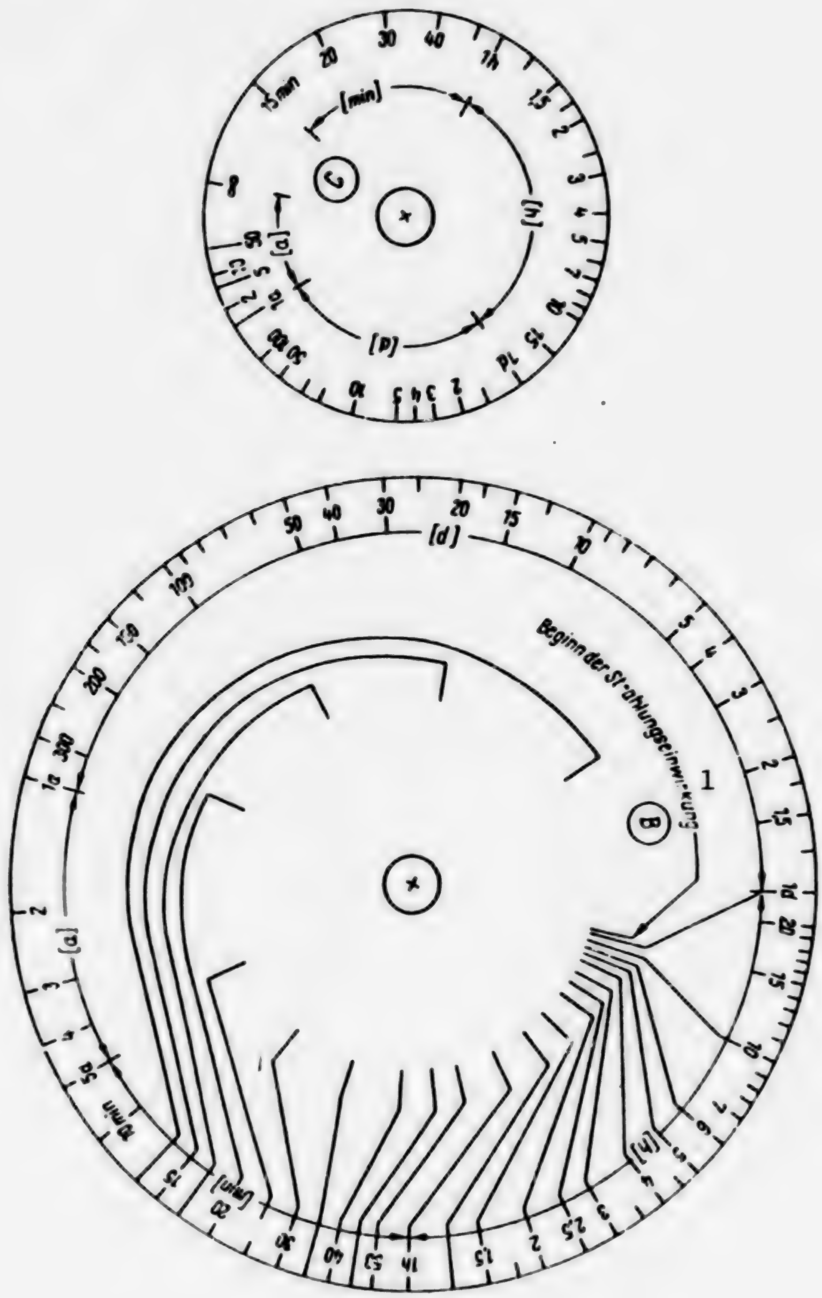

Key: 1--Start of radiation effect.

PHOTO CAPTIONS

Figure 1.2. The Trinity-Test, United States, 16 July 1945. The 214-t experimental setup prior to detonation[6] (from: Groueff, St., "Projekt ohne Gnade" [Project without Mercy], Guetersloh, 1968, p 293).

Figure 1.3. The first experimental detonation. a--After 0.006 sec; b--After 0.053 sec; c--After 10 sec; d--After 15 sec[6] (from: Groueff, St., "Projekt ohne Gnade," Guetersloh, 1968, pp 294-295).

Figure 1.4. Area around ground zero before and after detonation in Nagasaki.[10]

Figure 1.5. I. V. Kurchatov, the creator of the Soviet nuclear weapon.

[p 103] Figure 2.5. Detonation crater after Sedan test (United States). During the "Sedan test" in the United States on 6 July 1962, a nuclear charge of 100 kt was exploded at a depth of 194 m. The detonation crater formed had the following dimensions: Diameter 370 m, depth 97 m, quantity of soil ejected 5 million m^2, maximum crater pile-up height 30 m.

[p 104] Figure 2.6. Possible barrier effect of high-intensity ground blast in river valley. Top: Terrain prior to detonation; bottom: Terrain after detonation.

[p 115] Figure 2.10. Typical picture of air blast in kiloton range.[4]

[p 121] Figure 2.13. Typical picture of underground detonation at shallow depth.[27]

[p 124] Figure 2.15. Typical picture of development of underwater detonation in kiloton range (second development phase).[29]

[p 182] Figure 3.22. Light-weight brick house prior to detonation (Nevada testing ground).[14]

[p 182] Figure 3.23. Light-weight brick house after detonation at overpressure of 0.35 kp cm^{-2} (Nevada testing ground).[14]

[p 183] Figure 3.24. Concrete intermediate walls in this building were crushed. Roof and floor collapsed. Distance 160 m from ground zero in Hiroshima.[14]

[p 184] Figure 3.25a. Street prior to high-altitude air burst along border of near zone.

[p 184] Figure 3.25b. Street after detonation.

[p 185] Figure 3.26. The 70-cm thick brick walls of this building were smashed by the air pressure. Distance 550 m from ground zero in Nagasaki.[14]

[p 191] Figure 3.28. Streets blocked after nuclear weapon detonation in Hiroshima.[14]

[p 191] Figure 3.29. Stone bridge in area of near zone after low-altitude air burst of minor intensity.

[p 193] Figure 3.30. Development of windbreak zones due to effect of blast wave on forests.

[p 228] Figure 4.12. Typical profile burns on the head of a man.[13] Partial protection against light radiation produces sharply delimited burn wounds. The cap on the right is enough to protect the forehead. Distance about 2 km from ground zero.

[p 229] Figure 4.13. Contact burns due to contact of skin with heated clothing.[14] Even the skin covered by clothing was damaged. The unburned portions on the shoulders and on the back can be explained by the fact that the person wore a shawl or that the clothing did not stick closely to the body (air cushion).

[p 230] Figure 4.14. Contact burns of differing degree due to influence of clothing color.[15] The kimono's dark pattern was burned into the victim's skin because it absorbs light radiation much more than the bright places.

[p 240] Figure 4.15. Effect of light radiation on wooden house (Nevada test range, $U = 25$ cal cm^{-2}).[22] a--Immediately after detonation; b--2 sec later; the blast wave blew out the beginning fire.

[p 241] Figure 4.16. Burn places produced by light radiation on the asphalt of a bridge in Hiroshima. The railing partly left the asphalt undamaged because of its shadow. The length and direction of the shadows made it possible to determine the detonation center.[22]

[p 241] Figure 4.17. Burn places on upholstered chairs standing by the window and thus exposed to light radiation. Distance 1.6 km from ground zero in Hiroshima.[22]

[p 242] Figure 4.18. The paint on the gas tank was burned off by light radiation except in those places where it was shielded by the valve. Distance 2.2 km from ground zero in Hiroshima.[22]

[p 242] Figure 4.19. Roofing tile one half of which is covered with bubbles due to the effect of light radiation; the other half was masked by the superposed shingle. Distance 0.6 km from ground zero in Hiroshima.[22]

[p 444] Figure 7.43. Model SPW [APC] 40 P 2 (Ch) reconnaissance vehicle.

[p 454] Figure 7.47. DA-66 shower system.

[p 455] Figure 7.48. The ARS-12u decontamination vehicle.

[p 456] Figure 7.49. The EA-65 radioactive decontamination system.

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